LEARNING-BY-DOING IN DYNAMIC GENERAL EQUILIBRIUM MODELS: MACROECONOMIC IMPLICATIONS AND ESTIMATES

by

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Abstract

This thesis develops and estimates a structural model in which organizations, engaged in the process of production, acquire knowledge that raises their productivity. This knowledge is treated as an organization specific capital good, that is jointly produced with output and embodied in the organization itself. This organizational capital is accumulated subject to an accumulation technology that implies production units faces a trade-off between maximizing current period profits and losing future productivity increases. This thesis shows that this dynamic structure, which has previously been ignored in existing studies of learning-by-doing, might have important economic implications.

The results presented in this thesis contribute to our knowledge of the macroeconomic effects associated with the accumulation of organizational capital by focusing exclusively upon the accumulation of organizational capital by production units. This thesis establishes that when production experience is accumulated and stored by production units the implied values of several key macroeconomic variables in the non-stochastic steady state will be quite different to those implied by an otherwise identical model that ignores the accumulation of organizational capital. It is also shown that the accumulation of organizational capital generates a hump-shaped dynamic response of output to a fiscal policy shock. This hump-shaped output response is an important feature of the empirical dynamic responses. More importantly, a model that ignores organizational capital is unable to produce dynamic responses in output and investment that exhibit this hump-shaped response. Consequently, the dynamic responses associated with the accumulation of organizational capital might be consistent with the stylized facts associated with the empirical responses. These results suggest that the accumulation of production experience by production units will likely to be an important component of the endogenous propagation mechanism identified by Cooper & Johri (2002).

These macroeconomic effects arising from the accumulation of organizational capital rely critically upon the existence of a dynamic structure, at the plant level, associated with the accumulation of organizational capital. The results presented in this thesis suggest that this dynamic structure will be empirically important for production units across a diverse range of (manufacturing) industries. Consequently,

existing studies of learning-by-doing that aim to quantify the productivity of (accumulated) production experience without also considering the (endogenous) accumulation of this production experience are likely to be seriously flawed.

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Contents

List of Figures

List of Tables

1 Introduction

1.1 Introduction

This thesis develops and estimates a model in which organizations, engaged in the process of production, acquire knowledge that raises their productivity. This knowledge is treated as an organization specific capital good, that is jointly produced with output and embodied in the organization itself.

At least as far back as Marshall, economists have suggested that organizations store and accumulate knowledge that affects their technology of production.[1] The returns to this production knowledge are generally associated with the concept of learning-by-doing. Numerous studies recognize the importance of this learning-by-doing for explaining observed economic phenomena. Economic growth theorists make reference to learning-by-doing as a source of endogenous growth in which endogenous technical change is driven by the accumulation of knowledge.[2] Considerations of learning-by-doing also feature prominently in the industrial organization literature. In the presence of learning-by-doing, firms might find it optimal to overproduce in early periods of their life in order to invest in cost reduction. This suggests that incumbent firms may gain an absolute cost advantage over potential entrants and erect entry barriers.[3] These strategic outcomes will affect optimal industrial policies such as anti-trust policy and strategic trade policy. Since learning-by-doing leads to a form of dynamic returns to scale in which greater production rates lead to greater productivity over time, it provides a justification, at least theoretically, for trade barriers that protect infant industries. At the macroeconomic level, Cooper & Johri (2002) show that learning-by-doing may be a powerful mechanism for generating the endogenous persistence of shocks within the context of a stochastic dynamic

[1] Marshall (1961) states that "capital consists in a great part of knowledge and organization... [so that]...it is best to reckon Organization as a distinct agent of production" (p115).

[2] See Romer (1984).

[3] See Ghemawat & Spence (1985), Jarmin (1994).

general equilibrium model so that aggregate variables, particularly output, exhibit the persistence observed in the data.

There is an extensive empirical literature that explores the relationship between production experience and plant productivity. The typical study of learning-by-doing involves estimating how production input requirements decrease as production experience accumulates. Alternatively, these learning effects are expressed as the reduction in unit costs of production associated with the accumulation of production experience. The standard measure of production experience used in this learning curve literature is the cumulative number of units produced since the birth of the organization. Although these studies cover a diverse range of industries, there is somewhat of a consensus for the 20% learning curve where a doubling of cumulative output leads to a 20% reduction in unit costs of production.[4]

Alternatively, after noting that almost 9% of manufacturing output is not accounted for as payments to labour and physical capital, Atkeson & Kehoe (2002) build a model to measure how much of this output might be attributed to payments to production experience. They find that approximately 4% of output might be accounted for as payments to production experience. This suggests that the accumulation of production experience is an important component of national income.

Both the microeconomic evidence from traditional studies of learning-by-doing and the aggregate evidence provide considerable support for the stock of experience as a productivity enhancing factor of production. Although this empirical support for the pervasive presence of learning-by-doing effects in the economy is important, interest in the economic implications of allowing for the accumulation of production experience is ultimately motivated by a desire to understand how economic policy should be conducted in the presence of these learning effects.

Of course, the appropriate policy response will depend upon the sources of these learning effects. For example, the policy response to production experience that is accumulated by individuals might be quite different to the appropriate policy response to production experience that is accumulated by production units. Similarly, the appropriate policy response will depend upon whether production experience is

[4]Argote et al. (1990), Epple et al. (1991), Bahk & Gort (1993) and Benkard (2000) provide numerous references to this historical literature.

transferable across production units. Before, any such policy conclusions can be reached it is important to understand the economic implications arising from the presence of these alternative forms of learning-by-doing.

This thesis considers the economic implications arising from a particular form of production experience. Specifically, it focuses upon production experience that is accumulated and stored by the production unit. This implies that the (optimal) decision of how much output to produce is actually a joint decision on how much production experience to accumulate which affects future decisions regarding output. In this sense, production experience provides production units with knowledge about the optimal way to produce that lowers costs in the future.

Although there may be considerable transfer of this knowledge across production units either within the same organization or within the same industry, this thesis concentrates upon production experience that is entirely specific to the production unit. This reflects the fact that a significant portion of the knowledge associated with production experience might be quite specific and difficult to transfer. Consequently, this thesis focuses upon production experience that is proprietary to the organization and only transferable through the sale of the organization (or its individual production units).

For the purposes of this thesis, this production experience will be labelled as *organizational capital*. This reflects the nature of this production experience—knowledge that is embodied in the organization itself.[5] It also serves to reinforce the idea that this production experience shares some common features with other forms of capital. Just as the creation of physical capital involves a costly utilization of resources in order to generate a future stream of benefits, the accumulation of production experience involves a sacrifice of current period profits in order to generate a stream of future benefits. Higher (current) production rates, which involve an increase in current costs of production with no immediate effect upon productivity lead to the accumulation of experience and a reduction in future unit costs of production.

Consistent with this interpretation of production experience, this organizational capital is treated as an input in the production technology of production units.

[5] Note that this organizational capital is accumulated through production experience. It does not include other organizational assets that result from an often costly utilization of resources such as research and development expenditures.

In the presence of learning-by-doing, production units create organizational capital as a by-product of production such that the stock of organizational capital is modelled as a function of last period's level of production and the level of organizational capital available to the production unit. Formally, the stock of organizational capital is treated as a state variable at the level of the production unit.

This thesis presents a structural model that may be used to study the accumulation of production experience when production experience is accumulated and stored by production units. The next two chapters focus primarily upon the predictions from this structural economy for key macroeconomic variables. Interest in the macroeconomic implications arising from the accumulation of production experience is primarily motivated by the need to address the weak internal propagation mechanism of the standard neoclassical growth model. As shown by Cooper & Johri (2002), the accumulation of production experience might be capable of generating an internal propagation mechanism beyond that associated with the accumulation of physical capital. However, by focusing upon the choice problem solved by a social planner, they do not need to address whether this organizational capital is accumulated and stored by households or production units. In contrast, Chang et al. (2002) study this internal propagation mechanism when production experience is accumulated as a by-product of market work and stored by individuals. In conjunction with the results provided in both Cooper & Johri (2002) and Chang et al. (2002), this thesis contributes to our understanding of this endogenous propagation mechanism by studying a particular decentralization of the Cooper & Johri (2002) model in which organizational capital is accumulated only by production units.

Treating the stock of organizational capital as a productivity enhancing factor of production implies that the accumulation of production experience might be associated with a production technology that exhibits increasing returns to scale. In this case, it is inappropriate to assume that production units operate in a perfectly competitive product market.[6] Consequently, the accumulation of production experience cannot be studied without also considering market structure. This thesis incorporates monopolistic competition as one such market structure that would be consistent with

[6] In the presence of increasing returns, the absence of monopoly profits would imply that production units cannot generate enough revenue to pay for their desired inputs.

an increasing returns to scale production technology. This is perhaps the simplest market structure consistent with imperfectly competitive product markets.

The assumption of imperfectly competitive product markets introduces an important dynamic structure into the optimization problem of production units. When these production units face a downward sloping demand curve for their product, they recognize that charging a higher price today results in less output being sold. However, this lower output will also result in a lower stock of production experience in the future with consequently higher future costs of production. Fundamentally, these production units face a trade-off between maximizing current period profits and losing future productivity increases. This trade-off has previously been ignored in existing studies of learning-by-doing.

The next two chapters evaluate the importance of this decentralization by comparing the predictions of this structural model to a standard dynamic equilibrium general model that ignores these learning effects. It is established that when production experience is accumulated and stored by production units, the implied values of several key macroeconomic variables in the non-stochastic steady state might be quite different from those implied by an otherwise identical model that ignores the accumulation of organizational capital. It is also shown that the accumulation of production experience by households, as a by-product of market work, might imply a different steady state compared to the accumulation of production experience as a joint product with the production of goods and services. Although these results are important, the macroeconomic effects of allowing for the accumulation of organizational capital by production units can only be fully understood by also studying the dynamic response of the aggregate economy to exogenous disturbances that temporarily perturb the aggregate economy away from its steady state. The structural model is used to evaluate the response of output, consumption, investment, and employment to an unanticipated aggregate demand shock in the form of a deviation in government consumption from its long run level. Since the macroeconomic implications of learning effects in the presence of such an aggregate demand shock have not been previously studied, this chapter provides some interesting results that improve our understanding of the macroeconomic effects of changes in fiscal policy.

Having established that this dynamic structure associated with the interaction of learning-by-doing and market structure might have important consequences for the aggregate economy, the final chapter provides some new estimates of learning effects at the plant level, taking account of these interactions. These estimates are obtained by directly estimating the first order conditions from the maximization problem of the production unit. This strategy avoids many of the problems associated with estimates of these learning effects obtained by estimation of the production technology. More importantly, the practice of estimating these learning effects from the production technology ignores the dynamic structure implied by considerations of market structure. This chapter uses a dataset that covers all manufacturing plants in Canada which provides a more extensive study of these learning effects than previous studies that have concentrated upon specific industries or organizations.

1.2 What is Organizational Capital?

Organizational capital represents knowledge that evolves with production experience and enables the production unit to combine its physical and human capital inputs in a more efficient way. The existing literature contains two limiting views of this organizational capital. Several authors view this organizational capital as being embodied in employees and representing some form of match-specific capital.[7] In this case, organizational capital might represent knowledge about the abilities of individual employees, knowledge that improves the match between employees and specific tasks, or knowledge that improves the match between employees working in production teams. The distinguishing feature of this view is that a large portion of this organizational capital will be lost when workers leave the organization.

The alternative view is that organizational capital refers to knowledge that is jointly produced with output and embodied in the organization itself.[8] In general terms, organizational capital will represent the knowledge embodied in the organizational structures, systems, and procedures in place at the production unit. Although these organizational capital assets might depend upon the characteristics of current and past employees, these organizational assets are a durable feature of the organi-

[7] For example Prescott & Visscher (1980) and the considerable, largely microeconomic, literature that examines the accumulation of firm-specific human capital.

[8] For example Rosen (1972) and Bahk & Gort (1993).

zation itself. In this case, the stock of organizational capital will largely be invariant to employee turnover.

Obviously, these views of organizational capital represent two limiting cases such that the stock of organizational capital available to production units will likely represent knowledge embodied in both employees and the organization itself. However, this thesis restricts attention to this second interpretation of organizational capital as a specific capital good embodied in the organization. This restriction is largely motivated by a desire to understand the economic implications of allowing for production experience that is embodied solely in production units, particularly the implications for the aggregate economy, which have rarely been studied. With the exception of a few studies, existing microeconomic studies of learning-by-doing do not distinguish between knowledge embodied in employees and production units.

In order to restrict attention to this interpretation of organizational capital it is necessary to impose some simplifying assumptions upon the economy considered in this thesis. Specifically, it must be true that production units do not experience a reduction in their stock of organizational capital when workers leave their organization. When organizational capital is embodied in employees, such organizational capital will be (theoretically) indistinguishable from specific human capital. Consequently, it will be assumed that workers, with a given quantity of general human capital, will be perfect substitutes from the perspective of the production units. This essentially implies that production units operate within perfectly competitive labour markets so that all workers, with a given quantity of general human capital will receive identical compensation, regardless of where they are employed.[9] Without loss of generality, it may be assumed that all workers have the same quantity of human capital so that all workers receive identical compensation and all workers are perfect substitutes from the perspective of production units.

This assumption of no worker heterogeneity has several advantages. Firstly, it implies that heterogeneity in the performance of individual production units might be (reasonably) attributed to differences in the stock of organizational capital embodied in the organization. Secondly, it greatly simplifies the structure that needs to be

[9]When organizational capital is entirely embodied in the organization there is no reason to expect that workers would receive any of the returns to this organizational capital.

imposed in order to study the accumulation of organizational capital in the aggregate economy. Specifically, the accumulation of organizational capital may be studied using the structure of the standard one-sector neoclassical growth model.

In order to represent organizational capital as a specific capital good that is jointly produced with output, the stock of organizational capital will be described by an accumulation technology in which the stock of organizational capital depends upon last period's level of production and the level of organizational capital available to the production unit. Although this thesis considers both a log-linear and a linear accumulation technology, the critical features of this accumulation technology may be identified by considering the linear technology:[10]

$$Z_{t+1} = \phi_1 Z_t + \phi_2 Q_t \qquad \text{or} \qquad Z_t = \phi_1^t Z_0 + \phi_2 \sum_{j=0}^{t-2} \phi_1^j Q_{t-1-j} \tag{1}$$

where Z_t denotes the stock of organizational capital available to the production unit at time t, Z_0 denotes the initial endowment of organizational capital and Q_t denotes the level of output at time t. The parameter ϕ_1 captures the contribution of the (existing) stock of organizational capital, available at time t, to the stock of organizational capital Z_{t+1} and the parameter ϕ_2 captures the contribution of output at time t to the stock of organizational capital. The current stock of organizational capital will be a weighted sum of past output levels. The restriction $\phi_1 < 1$ implies that relatively distant production becomes less relevant over time. This suggests that cumulative output is not an appropriate measure of the stock of organizational capital. This accumulation technology will include the traditional measure of organizational capital as cumulative output when $\phi_1 = \phi_2 = 1$ and $Z_0 = 0$.

This "organizational forgetting" may arise in several contexts. When a production unit alters its product mix or changes the nature of its final output, the existing organizational structures that have evolved from production experience may become less relevant. The knowledge accumulated through production experience and represented by the current stock of organizational capital will be a function of the current stock of physical capital so that the decision to update technology by

[10] Argote et al. (1990) and Benkard (2000) consider a linear accumulation technology while Cooper & Johri (2002) and Johri & Letendre (2002) consider a log-linear accumulation technology.

replacing physical capital will imply that the existing stock of organizational capital will be less relevant to this new technology.

It can be seen that whenever production rates fall or are interrupted, there will be a loss of organizational capital. This suggests either strikes by employees, production congestions and bottlenecks or periods characterized by a downturn in demand will result in a reduced stock of organizational capital available to the production unit. Hence, recessions characterized by a general downturn in demand may lead to reductions in productivity that last longer than the reduction in output. Although the decision to upgrade technology is not explicitly modelled in this thesis, the decision to upgrade technology may not only involve a loss of specific organizational capital associated with the old technology but also a loss due to reduced output levels as the production unit learns about the new technology. Of course, the impact of past production interruptions will become less relevant over time.

The accumulation technology also allows for a varying contribution of (the weighted sum) of past output to the stock of organizational capital. Since it need not be true that each unit of current period output produce a unit of organizational capital, the parameter ϕ_2 controls the contribution of this current period output to the stock of organizational capital available to the production unit. This parameter essentially controls the productivity of investment in organizational capital.

This accumulation technology should not be interpreted as a precise and complete description of the evolution of organizational capital at the level of the production unit. Rather it is intended to capture parsimoniously some general factors that will affect the evolution of organizational capital at the level of the production unit. The particular functional form for the accumulation technology considered in this thesis is primarily motivated by the existing literature.

1.3 Previous Research and Motivation

The idea that organizations store and accumulate knowledge that affects their technology of production is not particularly new. There is an extensive empirical literature that explores the relationship between production experience and plant productivity. The typical study of learning-by-doing involves estimating how the production input requirements decrease as production experience accumulates. Alternatively, these learning effects are expressed as the reduction in unit costs of production associated with the accumulation of production experience. Cumulative output since birth of the organization is often used as a proxy for production experience. Although these studies cover a diverse range of industries, there is somewhat of a consensus for the 20% learning curve where a doubling of cumulative output leads to a 20% reduction in unit labour requirements.

This cumulative output since birth is used to construct a measure of the stock of production experience which is treated as a productivity enhancing factor of production. Variations in this stock of production experience will arise from variations in both the age of the organization and the rate of output. Care must be exercised when interpreting this age effect. Since this age effect may simply reflect input augmenting technical change, affecting the quality of the physical and labour input over time, it is necessary to decompose this age effect into embodied and disembodied technical change. Bahk & Gort (1993) are careful to decompose productivity enhancements into those that can be attributed to changes in inputs, measured in efficiency units, and those that are not embodied in labour or physical capital, a pure age effect. They introduce human capital (measured by the average wage rate) and the average vintage of physical capital as arguments in the production function, separate from raw labour and the physical capital. Using a dataset of new manufacturing plants they are able to construct two alternative measures of the stock of production experience—cumulative output since birth and the age of the plant. When experience is measured by the number of years since birth, the result indicate about a 1% increase in output per year. When experience is measured by cumulative output since birth, a doubling of cumulative output is associated with a 3.4% increase in current output. This increases to 7.9% when experience is measured as cumulative output per unit of labour input (to control for scale effects). These results suggest that a large portion of the traditional 20% learning rates can be associated with embodied input augmenting technical change.

It is important to recognize that the relevant stock of production experience need not be entirely determined by the cumulative output of the organization itself so that the stock of production experience might include external spillovers of experience either across organizations or across generations of final products. Irwin

& Klenow (1994) explore the importance of these external spillovers by estimating learning effects for seven generations of dynamic random access memory (DRAM) semiconductors. They estimate learning rates of approximately 20% in the semiconductor industry. In addition, they find that firms learn three times more from an additional unit of their own cumulative output than from an additional unit of another firms cumulative output. Despite this, the spillovers of production experience will likely be a significant source of productivity improvement. This result is consistent with the findings of Thornton & Thompson (2001) and Thompson (2001) for the Liberty War Time shipbuilding yards. Irwin & Klenow (1994) also find that intergenerational spillovers are weak, being economically relevant across generations of chips in only two of seven generations. This finding is consistent with the hypothesis of organizational forgetting in which relatively distant past production becomes less relevant over time.

Benkard (2000) extends the typical study of production experience by allowing for the depreciation of production experience.[11] Using data on inputs for the commercial aircraft building industry, he estimates an equation for labour requirements per aircraft. Production experience accumulates according to a linear accumulation technology which depends upon past production and past experience. Since Benkard has data on the entire history of output since birth he is able to construct a series for production experience. Without allowing for depreciation, he estimates a learning rate of 18% which is very close to the benchmark rate of 20% from previous studies. The introduction of depreciation of experience improves the fit of the model. A consequence of allowing for a constant rate of depreciation in the model is a much higher learning rate of approximately 40%—a doubling of experience would reduce labour requirements by 35–40%. The reason for this higher estimated learning rate is that the stock of production experience can no longer be measured by cumulative output. Instead, the learning rate should be measured relative to accumulated experience which is constantly depreciating (p 1049). The estimated monthly retention rate of experience of 96% implies 61% of the stock of experience existing at the start of the year survives to the end of the year. Note that this estimated retention rate

[11]Benkard (2000) uses an accumulation technology of the form given by (1) with $\phi_2 = 1$ and $0 < \phi_1 < 1$.

is considerably larger than the estimates obtained by Argote et al. (1990) for the Liberty Shipyards without instrumenting for production experience.

Since these studies of learning-by-doing focus upon specific industries or organizations, it is difficult to use these results to generalize to the aggregate economy. Using aggregate U.S. data, Johri & Letendre (2002) provide some estimates of the key structural parameters from the model of Cooper & Johri (2002). They estimate a learning rate of 18% and a quarterly retention rate for organizational capital of 95% which implies an annual retention rate of approximately 80%.[12] These results are based upon the assumption of constant returns to scale in the Cobb-Douglas production technology and a log-linear accumulation technology. Alternatively, Cooper & Johri (2002) investigate a specification that does not impose constant returns to scale in the production technology. After imposing constant returns to scale in physical capital and labour, Cooper & Johri (2002) report a learning rate of approximately 18% based upon production function estimation. It is this value that they use to calibrate their model.

The microeconomic evidence from the traditional studies of learning and the aggregate evidence suggests considerable support for both the stock of experience as a productivity enhancing factor of production and the hypothesis of organizational forgetting. This suggests that it is not appropriate to continue to ignore these learning effects in structural macroeconomic models.

The interest in the macroeconomic implications of allowing for the accumulation of production experience is primarily motivated by the need to address the weak internal propagation mechanism of the standard neoclassical growth model. As shown by Cooper & Johri (1997, 2002) and Johri & Letendre (2002), the accumulation of production experience might be a powerful mechanism for generating an endogenous propagation mechanism beyond the process of physical capital accumulation. These papers represent the choice problem of the representative agent through a stochastic dynamic programming problem solved by a planner. As such, they do not consider distinct households or production units and are not required to specify whether production experience is accumulated and stored by households or produc-

[12]This learning rate represents the effect upon current output of a doubling of the stock of organizational capital and is calculated directly from a production function parameter which parameterizes the effect of organizational capital on output.

tion units. Despite this, the interpretation of production experience in Stadler (1990) and Cooper & Johri (1997) is considerably different to that in Cooper & Johri (2002) and Johri & Letendre (2002).

As noted above, there is evidence that the spillover of production experience across production units might be empirically important. Partially motivated by this evidence, Stadler (1990) presents a model in which the aggregate production technology includes a scale factor that represents technical knowledge. This scale factor, which might be interpreted as external learning-by-doing, evolves according to a log-linear technology, similar to that considered in this thesis. Cooper & Johri (1997) present a somewhat more general (reduced form) representation of external learning-by-doing by including aggregate lagged output in the production technology. Although this dynamic complementarity might represent external learning-by-doing, this dynamic complementarity need not arise exclusively from such external learning-by-doing. Each individual production unit is assumed to be sufficiently small that they ignore the impact of their own output choices upon the stock of aggregate production experience. Although the accumulation of production experience might be associated with an aggregate technology that exhibits increasing returns to scale, the production technology of individual production units might display constant returns to scale. This ensures that the competitive equilibrium may be represented as a choice problem solved by a social planner. Primarily in the case of entirely external production experience, the existence of increasing returns in the social production technology will be consistent with individual production units operating in perfectly competitive product markets and producing according to a constant returns to scale production technology. Cooper & Johri (1997) show that external learning effects may be quite effective in propagating technology and preference shocks.

Although externalities associated with learning-by-doing might be potentially very important, it is not appropriate to focus exclusively upon such external effects. There is considerable evidence that the accumulation of production experience that is not transferable across production units might be also empirically important. In addition, the results of Irwin & Klenow (1994) and Thornton & Thompson (2001) suggest that these internal learning effects might be more important than external effects. Cooper & Johri (2002) present a model in which production experience is entirely internal to production units and show that such internal learning effects might be an important mechanism for generating the endogenous propagation of technology shocks. They represent the choice problem of the representative agent through a stochastic dynamic programming problem solved by a planner. As noted above, this has the advantage that it is not necessary to specify whether production experience is embodied in workers or production units. In the social planning solution of Cooper & Johri (2002), the representative agent recognizes that working harder today and consequently producing more output will result in higher productivity next period so that the labour supply decision becomes dynamic.[13]

Since production experience is likely to be accumulated by both households and production units, restricting attention to competitive equilibria that may be formulated as a choice problem solved by a social planner is quite convenient. However, such an approach is unable to identify whether the macroeconomic effects associated with the accumulation of production experience by households are fundamentally different from those effects associated with the accumulation of production experience by production units. As a first step in identifying these effects, Chang et al. (2002) present a decentralized version of the model presented in Cooper & Johri (2002) in which production experience is accumulated and stored by individuals.

Chang et al. (2002) motivate this particular decentralization by appealing to a substantial body of empirical work, primarily using microeconomic data, that provides evidence for a strong link between past labour supply and current wages. In contrast to the typical models of learning-by-doing, production experience accumulates as a by-product of market work.

Chang et al. (2002) impose some quite stringent restrictions upon their interpretation of production experience. Since all of the productivity effects associated with learning are captured by workers, the interpretation of production experience by Chang et al. (2002) is equivalent to a form of general human capital. This implies that all of the production experience, accumulated by workers, must be transferable across organizations. It is clear that this restriction is necessary so that the decentral-

[13]Intuitively, the representative agent will equate the current marginal disutility of work with the marginal utility of current consumption associated with the additional goods produced as well as the future marginal utility of additional goods produced next period induced by the accumulation of production experience. [Johri & Letendre (2002)].

ized equilibrium may be studied in the context of a representative agent framework. This decentralization is consistent with idea that the representative agent recognizes that working harder today and consequently producing more output will result in a higher return to market work in the next period so that the labour supply decision becomes dynamic. However, by restricting attention to experience that accumulates with hours of work, this decentralization is not a complete description of the equilibrium described in Cooper & Johri (2002). Primarily it excludes the mechanism whereby additions to the stock of production experience may be generated by investment in physical capital. Since the labour supply decision is directly related to the decision of how resources are allocated to consumption and investment, this decentralization ignores some potentially important dynamic effects that are present in the planning solution of Cooper & Johri (2002).

It is difficult to reconcile the structural model of Chang et al. (2002) with the results presented in Atkeson & Kehoe (2002). Since all of the productivity effects associated with learning are captured by workers, these effects will be measured as payments to labour at an aggregate level. This suggests that the almost 9% of manufacturing output that is not accounted for as payments to physical capital and labour, identified by Atkeson & Kehoe (2002), cannot reflect payments to production experience.

In contrast to Chang et al. (2002), this thesis presents an alternative decentralization of the model of Cooper & Johri (2002) in which production experience is accumulated as a joint product with output and stored by production units. In addition, this production experience is entirely specific to the organization.

As stated above, this decentralization is motivated by a desire to understand the nature of the endogenous propagation mechanism introduced by allowing for the accumulation of organizational capital. The next two chapters concentrate exclusively upon this endogenous propagation mechanism. In an effort to evaluate and further understand this propagation mechanism, these chapters compare an (aggregate) economy in which there is accumulation of organizational capital to an otherwise identical economy in which there is no accumulation of organizational capital.

1.4 Outline of the Thesis

The next chapter outlines a structural model that allows for the accumulation of organizational capital in the presence of monopolistic competition. A dynamic general equilibrium model of the aggregate economy is obtained from the optimizing behaviour of households and production units. Following a discussion of an appropriate strategy to calibrate this model so that the values of several key aggregate variables in the non-stochastic steady state of the model are consistent with the mean value of these variables in the data, several conclusions are discussed. Firstly it provides a detailed description of the non-stochastic steady state of the structural model. It examines the implications for the values of key macroeconomic variables in the non-stochastic steady state arising from alternative values for the organizational capital parameters. The estimates of the organizational capital parameters, provided in Cooper & Johri (2002), are measured with considerable standard errors. Consequently, it is important to understand how alternative values for these structural parameters might affect the steady state values.

The existing literature that explores the accumulation of production experience has considered two alternative functional forms for the accumulation technology. Cooper & Johri (2002) and Johri & Letendre (2002) consider a log-linear accumulation technology. In contrast, Argote et al. (1990), Epple et al. (1991) and Benkard (2000) consider a linear accumulation technology. The results presented in the next chapter reveal that when the parameters of these two accumulation technologies are identical, the non-stochastic steady state of the structural model will be more or less identical.[14] This suggests that the precise functional form of the accumulation technology might not be particularly important in describing the long run behaviour of key macroeconomic variables.

This next chapter also compares the steady state of this structural model to the steady state of an otherwise identical model that ignores the accumulation of organizational capital. Essentially, the values of the calibrated parameters in the organizational capital model are used to calibrate the structural parameters in this model that ignores the accumulation of organizational capital. This captures the

[14] Note that the linear technology implies quite a different "depreciation" rate of organizational capital compared to the linear technology.

idea that the macroeconomic data might be consistent with the structural model of organizational capital but the researcher has misspecified the true model of the aggregate economy. This provides some indication of the implications of ignoring the accumulation of production experience.

As noted above, demand shocks, which affect production rates, might have an important effect upon the stock of organizational capital available to the production unit. Within the context of a standard dynamic general equilibrium model of the aggregate economy, Chapter 3 describes how demand shocks might affect the aggregate economy when production units accumulate organizational capital. This aids in our understanding of the macroeconomic implications of allowing for production experience in several ways. The existing literature has primarily been concerned with studying the transitional dynamics associated with either technology shocks or preference shocks (which shift the marginal rate of substitution between consumption and leisure). As such, in conjunction with this previous research, this chapter provides a more complete description of the macroeconomic effects of allowing for the accumulation of production experience. Secondly, by studying the response of the model economy to an exogenous fiscal policy shock, this chapter provides some interesting results concerning the macroeconomic implications of a specific fiscal policy, beyond those obtained for the standard neoclassical growth model.

It is shown that there might be considerable differences between the transitional dynamics of the structural model compared to those for an otherwise identical model that ignores the accumulation of production experience. Importantly, it is shown that the dynamic responses associated with the accumulation of production experience exhibit a hump-shaped pattern which are an important characteristic of the empirical impulse responses. In contrast, the dynamic responses associated with the model, that ignores the accumulation of organizational capital are not characterized by this hump-shaped pattern.

Chapter 4 provides some estimates of the structural parameters associated with the accumulation of organizational capital by directly estimating the first order conditions from the plant's maximization problem. This avoids many of the biases associated with the estimation of these effects from production or cost functions. In contrast to existing studies of learning-by-doing, this estimation incorporates the dynamic structure implied by the joint hypothesis of monopolistic competition and the accumulation of organizational capital.

In contrast to existing research, this final chapter utilizes a lengthy panel of annual observations for a large cross section of Canadian manufacturing establishments. As such it provides a bridge between the microeconomic evidence for learning-by-doing in specific industries or organizations and the aggregate results of Cooper & Johri (2002) and Johri & Letendre (2002), while at the same time using observations collected at the plant level. The results indicate that the structure implied by the dynamic model of organizational capital cannot be rejected by the data. This suggests that the accumulation of organizational capital might be an important component determining the productivity of continuing manufacturing establishments.

2 A Structural Model of Organizational Capital—The Non-Stochastic Steady State

2.1 Introduction

The microeconomic evidence from both the traditional studies of learning-by-doing and the aggregate evidence provides considerable support for both the stock of experience as a productivity enhancing factor of production and the hypothesis of organizational forgetting. Beyond these productivity effects at the level of the production unit, the interest in the macroeconomic implications of allowing for the accumulation of organizational capital is motivated by a need to address the weak internal propagation mechanism of the standard neoclassical growth model. As shown by Cooper & Johri (2002), the accumulation of production experience might be capable of generating an endogenous propagation mechanism beyond the process of physical capital accumulation.

Typically, attention has been restricted to structural models that may be formulated as a choice problem solved by a social planner. These models do not consider distinct households and production units and are thus not required to specify whether production experience is accumulated by households or production units. Since production experience will likely be accumulated by both households and production units, this approach is quite convenient.[1] However, this approach is unable to identify whether the macroeconomic effects associated with the accumulation of production experience by households are fundamentally different than those effects associated with the accumulation of production experience by production units.

Chang et al. (2002) present a decentralization of the Cooper & Johri (2002) model in which production experience is only accumulated by households. Since all of the productivity effects associated with production experience are captured by

[1] This approach is particularly useful for studying external learning-by-doing.

workers, this interpretation of production experience is equivalent to some form of general human capital that accumulates with hours of market work. This implies that this production experience must be transferable across employers so that Chang et al. (2002) essentially restrict attention to external learning-by-doing.

Although external learning-by-doing might be potentially important, there is considerable evidence that the accumulation of production experience that is not transferable across organizations is also empirically important. In addition, the results in Irwin & Klenow (1994) and Thornton & Thompson (2001) suggests that internal learning effects might be more important than external effects.

This chapter develops a structural model of production experience that represents an alternative decentralization of the model presented in Cooper & Johri (2002). This production experience is accumulated as a by-product of production and is stored by production units. In addition, this production experience is entirely specific to the organization and consequently not transferable. This stock of organizational capital evolves according to an accumulation technology and is treated as an input in the production technology. This accumulation technology expresses the current stock of organizational capital as a function of last period's level of production and the stock of organizational capital available to the production unit. The main advantage of this accumulation technology is that it allows for a more general treatment of the evolution of the stock of organizational capital than that implied by typical studies of learning-by-doing. Formally, the stock of organizational capital is treated as a state variable in the optimization problem of the production unit.

This stock of organizational capital is interpreted as a durable feature of the organization itself that represents the knowledge embodied in the organizational structures, systems, and procedures that evolve with production experience and enable the production unit to combine physical and human capital inputs in a more efficient manner. Although the stock of organizational capital might depend upon the characteristics of current and past employees, this organizational capital represents that portion of knowledge that remains when workers leave the organization. This restriction is particularly useful since it suggests that any productivity effects associated with the accumulation of organizational capital are not likely to be shared with workers. In this case the assumption of a perfectly competitive labour market may be maintained.

This particular decentralization of the Cooper & Johri (2002) model is motivated by a desire to understand the nature of the endogenous propagation mechanism introduced by allowing for the accumulation of production experience. Although variations in the stock of specific organizational capital might be an important source of plant productivity differences, this chapter concentrates exclusively upon the effects of allowing for the accumulation of organizational capital upon the aggregate economy. In an effort to evaluate and further understand these aggregate effects, this chapter compares an (aggregate) economy in which there is accumulation of organizational capital to an otherwise identical economy in which there is no accumulation of organizational capital.

This chapter studies the properties of the non-stochastic steady state of a dynamic general equilibrium model that allows for the accumulation of organizational capital. Typically, studies of the macroeconomic implications of allowing for the accumulation of production experience focus upon the dynamic response of the aggregate economy to temporary exogenous shocks that perturb the economy away from its steady state. Since these dynamic responses will depend upon the value of key macroeconomic variables in the steady state, it is important to understand how the accumulation of organizational capital affects the values of macroeconomic variables in the steady state.

It is shown that when organizational capital is accumulated and stored by production units there are two important general equilibrium effects that do not arise in the decentralized model of Chang et al. (2002). Firstly, since organizational capital accumulates as a by-product with output, investment in physical capital will produce additions to the stock of organizational capital. As such, the accumulation of organizational capital will alter the physical capital to output ratio in the steady state.

Since organizational capital is treated as an input in the production technology of production units, the accumulation of organizational capital might be associated with *internal* increasing returns to scale at the level of individual production units. In this case, it is inappropriate to maintain the assumption that individual production units operate in a perfectly competitive product market. When production units face a downward sloping demand for their product, they realize that decisions regarding the optimal current output price will affect future productivity through the available stock of production experience. This dynamic structure has an important impact upon the values of key macroeconomic variables in the steady state and in particular alters the factor revenue shares in the steady state which also affect the steady state physical capital to output ratio.

The next section details how the standard model of monopolistic competition might be altered to allow for the accumulation of organizational capital. The assumption of monopolistic competition is seen as the simplest market structure that would be consistent with production units that have market power. It is shown that the assumption of market power, and in particular monopolistic competition, considerably complicates the calibration of such a dynamic general equilibrium model. The decision to calibrate the model so that the values of key macroeconomic variables in the steady state are consistent with mean values of these variables in the data may be motivated in several ways. Firstly, with the exception of a log-linear accumulation technology, estimation of the structural parameters would require a time series for the stock of organizational capital which will generally be unobservable. The calibration of the structural model allows a comparison between this log-linear technology, which has been used by Cooper & Johri (2002), and a linear accumulation technology which figures prominently in existing studies of learning-by-doing. An appropriate calibration strategy is able to investigate whether the functional form for the accumulation technology has any important implications for the aggregate economy.

Secondly, estimates of the productivity of organizational capital will depend upon the estimates of all of the structural parameters. The advantage of calibrating the model is that the partial effect of altering this productivity parameter may be investigated holding the accumulation parameters fixed. Since existing estimates of the organizational capital parameters are generally measured with considerable error, this strategy allows an evaluation of how alternative values for these organizational capital parameters might affect the steady state values.

These calibrated values for the structural parameters are then used to compare the steady state of this economy which allows for the accumulation of organizational capital to an otherwise identical economy that ignores the accumulation of organizational capital. Essentially, the values of the calibrated parameters in the organizational capital model are used to calibrate the structural parameters in the model that ignores the accumulation of organizational capital. This provides some indication of the implications of ignoring the accumulation of production experience. Firstly, the accumulation of organizational capital might raise the degree of aggregate returns to scale, relative to a model that ignores the organizational capital such that the true scale elasticity might be larger than that implied by the model which ignores production experience. Secondly, a model that ignores organizational capital fails to account for the dynamic structure in the plant's maximization problem associated with the accumulation of organizational capital. It is shown that both of these effects might have an impact upon the long run values of key macroeconomic variables implied by the organizational capital model, relative to a model that ignores the accumulation of organizational capital.

2.2 Description of the Model Economy

2.2.1 Final and Intermediate Goods Producers

Consider a continuum of intermediate goods producers operating within a monopolistically competitive economy each producing a differentiated good $q(j)$ with $j \in [0, 1]$ according to the following production technology:

$$q_t(j) = F\left[\, k_t(j),\, z_t(j),\, h_t(j)X_t \,\right] \tag{1}$$

where organizational capital $z_t(j)$ is combined with physical capital $k_t(j)$ and effective labour $h_t(j)\,X_t$ to produce output $q_t(j)$. Organizational capital is an accumulating factor of production that is predetermined in the sense that $z_t(j)$ reflects the stock of organizational capital available at time t and chosen in period $t-1$. The term X_t represents labour-augmenting technical progress, common across all producers.[2] By assumption, the production technology (1) exhibits positive and diminishing marginal

[2]As shown by King & Rebelo (1999) the feasibility of steady state growth, in which all variables grow at a constant rate, requires that the deterministic component of technical progress be expressible in a labour-augmenting form. However, for a Cobb-Douglas production function, labour-augmenting technical progress, physical capital-augmenting technical progress and total factor-augmenting technical progress will all be consistent with steady state growth.

productivity with respect to each input.

The level of technology X_t evolves according to:

$$X_t = X_{t-1} \exp(\psi_x + \zeta_t) \tag{2}$$

where ζ_t is a serially uncorrelated independently and identically distributed stochastic process with a mean of zero and a standard deviation of σ_ζ. Define the growth rate in the level of technology as:

$$g_X(t-1,t) = \frac{X_t - X_{t-1}}{X_{t-1}} \qquad \text{or} \qquad 1 + g_X(t-1,t) = \frac{X_t}{X_{t-1}}$$

Using the approximation $\ln(1+s) \approx s$ for s sufficiently close to zero, the (approximate) growth rate in the level of technology will be given by $g_X(t-1,t) \approx (\psi_x + \zeta_t)$. The unconditional (approximate) mean growth rate in the level of technology will be given by ψ_x. Therefore, the process (2) implies that the growth rate in the level of technology will be stochastic and any changes in the level of technology will be permanent.[3]

Organizational capital is accumulated according to:

$$z_{t+1}(j) = G\left[\, z_t(j)\, , q_t(j)\,\right] \tag{3}$$

where $G(\cdot)$ is increasing in both of its arguments. This accumulation equation might be viewed as a technology that uses the existing stock of organizational capital and current plant output as productive inputs.

Both the production technology (1) and the accumulation technology (3) are intended to capture some general features of the stock of organizational capital. Firstly, intermediate goods producers treat the stock of organizational capital as a state variable in their optimization problem so that the stock of organizational capital represents internal learning-by-doing. Secondly, the accumulation technology is consistent with the hypothesis of organizational forgetting, which has been

[3]This representation of the level of technology is motivated by Nelson & Plosser (1982) who provide empirical support for the idea that productivity contains a unit root. It also facilitates a comparison to existing research such as Christiano & Eichenbaum (1992) and Burnside & Eichenbaum (1996).

identified as empirically important in the learning-by-doing literature.[4] This accumulation technology captures the idea that whenever current production rates fall or are interrupted, there will be a loss of organizational capital.

Using these intermediate goods as inputs to a constant returns to scale production technology a final good is produced in a competitive industry by an arbitrary number of identical final goods producers. Given these inputs, the amount of the final good produced in a period is given by:

$$Y_t = \left\{ \int_0^1 [q_t(j)]^{1/\mu} \, dj \right\}^{\mu} \tag{4}$$

The elasticity of substitution between any two intermediate inputs in final goods production is given by $\mu/(\mu - 1)$ with $\mu > 1$ so that larger values of μ are associated with an elasticity of substitution closer to unity. As $\mu \to 1$ the elasticity of substitution becomes (infinitely) large so that intermediate goods may be interpreted as perfect substitutes in the production of the final good.

Operating within a perfectly competitive industry, a producer of final goods will have the following cost minimizing demand for the jth intermediate input, given the amount of the final good produced:

$$q_t(j) = v_t(j)^{\mu/(1-\mu)} Y_t \left\{ \int_0^1 [v_t(k)]^{1/(1-\mu)} \, dk \right\}^{-\mu} \tag{5}$$

where $v_t(j)$ is the price of the jth intermediate input.[5]

The cost function for a producer operating in the final goods sector will be given by:

$$C[Y_t, v_t(1), v_t(2), \ldots, v_t(J)] = Y_t \left\{ \int_0^1 [v_t(j)]^{1/(1-\mu)} \, dj \right\}^{1-\mu}$$

Since the final goods sector is competitive, the equilibrium price of the final good P_t must be equal to unit cost. Consequently, the unit cost function of a final goods

[4] See Argote et al. (1990) and Benkard (2000).

[5] Note that (5) is derived by solving the cost minimization problem of a final goods producer.

producer provides the following:

$$P_t = \left\{ \int_0^1 \left[v_t(j) \right]^{1/(1-\mu)} dj \right\}^{1-\mu}$$

The conditional factor demands for each intermediate input $q_t(j)$ that arise from the cost minimization problem, faced by the final goods producers, will represent the market demand function faced by each intermediate goods producer. The inverse demand function for intermediate goods producer j will be given by:

$$v_t(j) \left[q_t(j), P_t, Y_t \right] = \left\{ \frac{q_t(j)}{Y_t} \right\}^{\frac{1-\mu}{\mu}} P_t \tag{6}$$

where Y_t represents the output of the final goods sector. Using (6), the price elasticity of demand is given by $\mu/(1-\mu)$, the negative of the elasticity of substitution between any two intermediate inputs in final goods production.

It is useful to dissect the problem faced by an intermediate goods producer into two stages. In the first stage, the producer chooses the cost minimizing quantities of labour and physical capital, for a given stock of organizational capital, following the realization of the shock ζ_t to the level of technology X_t. Since physical capital and labour are assumed to be perfectly mobile, the intermediate goods producer j solves the following static cost minimization problem:

$$\min_{h_t(j), k_t(j)} \left\{ w_t h_t(j) + r_t k_t(j) \mid F\left[k_t(j), z_t(j), h_t(j) X_t \right] \geq q_t(j) \right\} \tag{7}$$

Each intermediate goods producer is assumed to operate within a perfectly competitive input market such that the (real) rental price of physical capital r_t and the (real) wage w_t are taken as given. This cost minimization problem produces conditional factor demands that are a function of factor prices, the required level of output (q_t) and the stock of organizational capital (z_t). The cost function, which represents the solution to the minimization problem defined by (7), will be a non-increasing function of the (given) stock of organizational capital. Since the cost function, will be linearly homogenous in the real rental price of physical capital and the real wage rate, the nominal cost function may be written as the product of the price level P_t and the real cost function.

In the second stage, the intermediate goods producer solves a dynamic problem that selects the time path of output supply q_t or output price v_t that maximizes the expected discounted present value of profits, subject to the inverse demand function (6), the accumulation technology for organizational capital (3), and the initial stock of organizational capital z_0. It is assumed that all intermediate goods producers are endowed with an initially positive and identical stock of organizational capital. There is no entry or exit by assumption so that the number of intermediate goods producers remains fixed.[6]

Each intermediate producer faces the following demand function:

$$q_t(j) = f\left[v_t(j), P_t, Y_t\right] = \left\{\frac{v_t(j)}{P_t}\right\}^{\frac{\mu}{1-\mu}} Y_t$$

Using this demand function, the Lagrangian associated with the maximization problem of jth producer of intermediate goods will be given by:

$$\max_{v_t, z_{t+1}} E_0 \sum_{t=0}^{\infty} \Big[\beta^t \left[v_t \cdot f(v_t, P_t, Y_t) - P_t \cdot C(w_t, r_t, X_t, f(v_t, P_t, Y_t), z_t)\right] \\ + \Lambda_t^f \left\{ G\left[z_t, f(v_t, P_t, Y_t)\right] - z_{t+1} \right\}\Big]$$

subject to the transversality condition $\lim_{t\to\infty} \Lambda_t^f z_t = 0$. The parameter β is a (common) discount factor satisfying $0 < \beta < 1$ and $\beta = 1/(1+\rho)$ where ρ is the rate of time preference. This discount factor β is assumed not to vary across the intermediate goods producers.

The stochastic nature of the problem arises because the producer must choose the (desired) stock of organizational capital z_{t+1} prior to the realization of the technology shock ζ_{t+1}. Expectations are assumed to be formed rationally so that E_t denotes both the mathematical expectation at time t and the subjective expectation at time t. It is assumed that all past and current realizations of the exogenous and control variables are known with certainty at the beginning of each period but there is uncertainty regarding future realizations of the exogenous variables. Specifically,

[6]As discussed below and in the next chapter, this is quite an important assumption.

expectations are formed, conditional upon the information set Ω_t which includes the realizations of the exogenous variables and the endogenous state variable z_t:

$$\Omega_t(j) = [w_t, r_t, \zeta_t, P_t, Y_t, z_t(j)]$$

Consequently, at time 0, the producer will have the information set Ω_0. The solution to this maximization problem will satisfy the following first order conditions (for all t):

$$\left[q_t + v_t \frac{\partial q_t}{\partial v_t}\right] - P_t \frac{\partial C_t}{\partial q_t}\frac{\partial q_t}{\partial v_t} + \frac{\Lambda_t^f}{\beta^t}\frac{\partial z_{t+1}}{\partial q_t}\frac{\partial q_t}{\partial v_t} = 0 \tag{8}$$

and

$$-\frac{\Lambda_t^f}{\beta^t} - \beta E_t \left\{ P_{t+1}\frac{\partial C_{t+1}}{\partial z_{t+1}} - \frac{\Lambda_{t+1}^f}{\beta^{t+1}}\frac{\partial z_{t+2}}{\partial z_{t+1}} \right\} = 0 \tag{9}$$

The first order condition (8) determines the optimal output price v_t to be set by the producer of the intermediate input j. Since the intermediate goods producer faces a downward sloping demand curve for their product, raising the output price by one unit causes demand for their product to fall. The first term in (8) captures the impact on current revenue of raising the price of output v_t. The second term represents the reduction in current period costs resulting from the corresponding lower level of output. The accumulation technology for organizational capital implies that a reduction in current output will lead to a reduction in the stock of organizational capital available in the next period. The final term in (8) represents the value of this reduced (future) stock of organizational capital. The term $\partial q_t / \partial v_t$ measures the reduction in current output due to the higher output price and the term $\partial z_{t+1} / \partial q_t$ represents the reduction in the (future) stock of organizational capital resulting from the reduction in current period output, evaluated at the marginal value of organizational capital to the intermediate goods producer.

The first order condition (8) captures the nature of the dynamic trade-off that arises when intermediate goods producers face a downward sloping demand curve. Fundamentally, these producers face a trade-off between maximizing current period profits and losing future productivity increases. This tradeoff is captured by the (dynamic) third term in (8) that will not appear in the standard model of monopolistic competition without the accumulation of organizational capital.

The first order condition (9) determines the value of an additional unit of organizational capital for use by the producer in period $t+1$. This additional unit of organizational capital has a (marginal) value, in terms of profits, of Λ_t^f/β^t to the producer. Since the cost function is decreasing in the stock of organizational capital, an additional unit of organizational capital reduces the cost of producing output level q_{t+1}. The accumulation technology for organizational capital implies that an additional unit of organizational capital will increase the stock of organizational capital available in period $t+2$. This higher stock of organizational capital has a value of $\Lambda_{t+1}^f/\beta^{t+1}$ to the producer. The condition (9) implies that organizational capital will be accumulated up to the point where the value of an additional unit of organizational capital today is equal to the discounted value of this organizational capital next period.

2.2.2 Households

The economy is populated by a large number of identical, infinitely lived households. At time t the representative household has preferences over individual consumption of final goods $\tilde{c}_t$ and leisure $\tilde{l}_t$. Each member of the household is endowed with a total time endowment T which may be allocated to market work $\tilde{h}_t$ or leisure $\tilde{l}_t$. The representative household seeks to maximize:

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \, N \, u(\tilde{c}_t, T - \tilde{h}_t) \right\}$$

where β denotes the discount factor used by households to discount future utility flows, N denotes the number of members of the household which is assumed not to vary over time, $\tilde{c}_t$ denotes per-capita consumption by members of the household in period t, and $\tilde{h}_t$ denotes the per-capita hours devoted to market work by members of the household in period t.[7] By normalizing the number of households to one so that N represents the total population of the economy, aggregate consumption C_t will be given by $(N\,\tilde{c}_t)$.

The household's objective is to maximize the discounted stream of per-capita

[7]It is assumed that households discount future utility at the same rate used by intermediate goods producers to discount future profits.

utility by choosing the optimal quantity of final goods to consume $\tilde{c}_t$ or invest in physical capital $\tilde{i}_t$ and the number of hours to devote to market work $\tilde{h}_t$, taking as given the price of the final good P_t, the real wage w_t and the real return on physical capital r_t. Each member of the household sells labour services and rents physical capital to the intermediate goods producing firms. As owners of all intermediate goods producing firms, the household also receives the current profits of these producers.

Physical capital is stored by households and accumulated according to a standard intertemporal accumulation technology. The law of motion for the aggregate physical capital stock is given by:

$$K_{t+1} = (1-\delta)\,K_t + I_t$$

where δ is the depreciation rate and I_t denotes aggregate investment in physical capital at time t, in units of the final good. Denoting the per-capita physical capital stock at time t by $\tilde{k}_t$, the household's maximization problem becomes:

$$\max_{\tilde{c}_t,\tilde{h}_t,\tilde{k}_{t+1}} E_0 \sum_{t=0}^{\infty} \Bigg[\beta^t\, N\, u(\tilde{c}_t, T-\tilde{h}_t) + \Lambda_t^h \left\{ w_t \tilde{h}_t + r_t \tilde{k}_t + \frac{1}{N\,P_t}\int_0^1 \pi_t(j)\,dj - \frac{\tau_t}{P_t} - \tilde{c}_t - \tilde{k}_{t+1} + (1-\delta)\tilde{k}_t \right\} \Bigg]$$

subject to the transversality condition $\lim_{t\to\infty} \Lambda_t^h \tilde{k}_t = 0$ and an initial stock of physical capital $\tilde{k}_0$. The expectation operator appears in the maximization problem because the household faces uncertainty about its future income. Specifically there is uncertainty regarding the future realizations of the exogenous variables. Expectations are formed, conditional upon the information set Ω_t which includes the realizations of the exogenous variables and the endogenous state variable k_t:

$$\Omega_t(j) = \left[w_t, r_t, \zeta_t, P_t, Y_t, \tilde{k}_t \right]$$

Consequently, at time 0, the producer will have the information set Ω_0. The term τ_t represents a lump sum tax paid by each member of the household that is used to finance government consumption of the final good. The government is required to balance its budget each period so that $P_t\,G_t = N\,\tau_t$. It is assumed that government consumption does not directly alter the marginal utility of private consumption or the productive capital stock so that government consumption is a pure resource drain on the economy.

This treatment of the government sector is probably the simplest way that government consumption might be introduced into the model. It may be motivated in several ways. Firstly, the structure has become quite standard in structural dynamic general equilibrium models and consequently facilitates a comparison with existing models of economic fluctuations.[8] Since the aim is to isolate the impact of government consumption, it seems entirely reasonable to assume the existence of lump sum taxation so that this government consumption is financed in a non-distortionary manner. The restriction that the government balance its budget every period avoids the need to formally model a market for government debt.

The solution to this maximization problem will satisfy the following first order conditions (for all t):

$$\frac{\partial u(\tilde{c}_t, T-\tilde{h}_t)}{\partial \tilde{c}_t} - \frac{\Lambda_t^h}{\beta^t N} = 0 \tag{10}$$

$$-\frac{\partial u(\tilde{c}_t, T-\tilde{h}_t)}{\partial (T-\tilde{h}_t)} + w_t \frac{\Lambda_t^h}{\beta^t N} = 0 \tag{11}$$

$$-\Lambda_t^h + E_t\left\{\Lambda_{t+1}^h\left[r_{t+1} + (1-\delta)\right]\right\} \tag{12}$$

Alternatively, these first order conditions may be written as the following:

$$-\frac{\partial u(\tilde{c}_t, T-\tilde{h}_t)}{\partial (T-\tilde{h}_t)} = w_t \frac{\partial u(\tilde{c}_t, T-\tilde{h}_t)}{\partial \tilde{c}_t} \tag{13}$$

and

$$\frac{\partial u(\tilde{c}_t, T-\tilde{h}_t)}{\partial \tilde{c}_t} = \beta E_t\left\{\frac{\partial u(\tilde{c}_{t+1}, T-\tilde{h}_{t+1})}{\partial \tilde{c}_{t+1}}\left[r_{t+1} + (1-\delta)\right]\right\} = 0 \tag{14}$$

The interpretation of these first order conditions is quite standard. Condition (13)

[8]In the standard neoclassical growth model, this structure is typically motivated by appealing to Ricardian equivalence. When government consumption is financed by lump sum taxation, the time path of government debt will be of no consequence provided this government debt satisfies an appropriate transversality condition. In this case, it is reasonable to assume that the government faces a balanced budget constraint in every period.

requires per-capita consumption and hours be chosen so that the marginal rate of substitution between per-capita consumption and leisure, for all t, is equal to the real wage rate. Condition (14) is the standard Euler equation for the accumulation of physical capital which requires that, at the optimal solution, the utility cost of giving up one unit of consumption must be equal to the present value (in terms of utility) of this unit of consumption next period.

2.2.3 Equilibrium Prices and Quantities

A competitive equilibrium will consist of:

1. allocations $\{\tilde{c}_t, \tilde{h}_t, \tilde{k}_{t+1}\}$ that solve the consumer's problem, taking prices as given
2. allocations $\{h_t(j), k_t(j), z_{t+1}(j)\}$ for $j \in [0,1]$ that solve the intermediate goods producer's problem, taking all prices but their own output price as given, subject to the accumulation technology and the inverse demand function
3. allocations $\{q_t(j), Y_t\}$ that solve the final goods producer's problem, taking prices as given.
4. prices $\{v_t(j), P_t, w_t, r_t\}$ for $j \in [0,1]$

In addition these allocations must satisfy the factor market clearing conditions and the aggregate resource constraint.

Since the technology of the economy is assumed symmetric with respect to all intermediate goods producers, attention may be restricted to the symmetric equilibrium where all producers in the intermediate goods sector charge the same price and produce the same output. In this case:

$$Y_t = \left\{ \int_0^1 [q_t(j)]^{1/\mu} \, dj \right\}^{\mu} = q_t^{1/\mu} \left[\int_0^1 dj \right]^{\mu} = q_t$$

and

$$P_t = \left\{ \int_0^1 [v_t(j)]^{1/(1-\mu)} \, dj \right\}^{1-\mu} = v_t^{1/(1-\mu)} \left[\int_0^1 dj \right]^{1-\mu} = v_t$$

so that symmetry requires the relative price $v_t/P_t = 1$. Since all intermediate goods producers have the same level of technical progress and have the same initial endowment of organizational capital, it will be true that, for all j, $h_t(j) = h_t$, $k_t(j) = k_t$, and $z_t(j) = z_t$. In this case, the total demand for hours and the total demand for physical capital will be given by:

$$\mathbf{H_t^D} = \int_0^1 h_t(j)\, dj = h_t \qquad \text{and} \qquad \mathbf{K_t^D} = \int_0^1 k_t(j)\, dj = k_t$$

with the aggregate stock of organizational capital given by:

$$\mathbf{Z_t} = \int_0^1 z_t(j)\, dj = z_t$$

The total profits of all intermediate goods producers will be given by:

$$\mathbf{\Pi_t} = \int_0^1 v_t(j) q_t(j)\, dj - P_t\, w_t \int_0^1 h_t(j)\, dj - P_t\, r_t \int_0^1 k_t(j)\, dj$$

In the symmetric equilibrium, $q_t(j) = q_t$, $k_t(j) = k_t$, $h_t(j) = h_t$, $z_t(j) = z_t$ with $v_t(j) = v_t = P_t$ so that total profits in the intermediate goods sector will be:

$$\mathbf{\Pi_t} = v_t\, q_t - P_t\, w_t \mathbf{H_t^D} - P_t\, r_t \mathbf{K_t^D} = P_t\, Y_t - P_t\, w_t \mathbf{H_t^D} - P_t\, r_t \mathbf{K_t^D}$$

This may be further simplified by noting that

$$Y_t = q_t = F\,[\,k_t\,, z_t\,, h_t X_t\,] = F\,\left[\,\mathbf{K_t^D}\,, \mathbf{Z_t}\,, \mathbf{H_t^D} X_t\,\right]$$

Substituting this expression for the total profits of intermediate goods producers into the household budget constraint and using the government budget constraint provides the following:

$$N\, w_t\, \tilde{h}_t + N\, r_t\, \tilde{k}_t + Y_t - w_t \mathbf{H_t^D} - r_t \mathbf{K_t^D} - G_t - N\, \tilde{c}_t - N\, \tilde{k}_{t+1} + (1 - \delta)\, N\, \tilde{k}_t = 0$$

where the total supply of labour will be given by $(N\, \tilde{h}_t)$ and the total supply of physical capital will be given by $(N\, \tilde{k}_t)$. The level of aggregate consumption will be given by $N\,\tilde{c}_t$. In addition to the first order conditions arising from the maximization problems of households and intermediate goods producers, the equilibrium allocations must satisfy market clearing conditions in the input markets for labour and physical capital.[9] Using these factor market clearing conditions, which require that $\mathbf{H_t^D} = N\,\tilde{h}_t$ and $\mathbf{K_t^D} = N\,\tilde{k}_t$ the household's period t budget constraint provides the following aggregate resource constraint:

$$C_t + K_{t+1} - (1-\delta)\,K_t + G_t = Y_t \tag{15}$$

2.2.4 Some Functional Forms

Let the flow utility of the representative household be given by:

$$N\,u(\tilde{c}_t, T - \tilde{h}_t) = N\left[\ln(\tilde{c}_t) + \Phi\,(T - \tilde{h}_t)\right] \tag{16}$$

In this case, the representative agent has preferences that are *linear* in leisure implying an infinite λ-constant elasticity of labour supply.[10] Alternatively, these preferences may be interpreted as a reduced form preference ordering when labour supply is indivisible. Under this interpretation, individuals may choose either to work a fixed shift of length h_0 or not at all. Assuming that individuals have preferences that are separable in consumption and leisure, Rogerson (1988) shows that there exists a Pareto-optimal allocation of consumption and leisure in which individuals choose a contract that commits the individual to work h_0 with some probability p_t. Within the general class of preferences which imply exactly offsetting income and substitution effects from permanent changes in real wages, Hansen (1985) shows that the preferences of the representative agent may be expressed in the form given by (16). The critical feature of this indivisible labour economy lies in the divergence between the preference relation of the individual and the representative agent. Although each individual agent might have a relatively low labour supply elasticity that is consistent with the microeconomic data, the aggregate economy behaves as if it is populated by

[9] By Walras' Law these market clearing conditions in factor markets will imply that the market for final goods will also clear.

[10] Browning et al. (1999) provide a general discussion of the λ-constant elasticity of labour supply and King & Rebelo (1999) provide a discussion of this elasticity with reference to the utility function given by (16).

agents with an infinite elasticity of labour supply.

One implication of the labour supply behaviour in this indivisible labour economy is that the demand side of the labour market will determine the equilibrium quantity of employment and consequently total hours of work. These indivisible labour preferences might be motivated in several ways. Firstly, they are quite common in dynamic general equilibrium models of the aggregate economy and thus facilitate a comparison to previous research, particularly Cooper & Johri (2002). Secondly, the structural model outlined above involves the accumulation of organizational capital by production units. Since it is assumed that none of the productivity effects of organizational capital are shared with workers, it seems appropriate to assign a passive role to the labour supply decision of the representative agent. Of course, in the model of Chang et al. (2002), in which experience is accumulated by households, these preferences would not be appropriate.

Let the production technology of each (symmetric) producer of intermediate goods be given by:

$$q_t = k_t^{\theta}\, z_t^{\varepsilon}\, (h_t X_t)^{\alpha} \qquad 0<\alpha<1 \quad 0<\theta<1 \quad 0<\varepsilon<1 \tag{17}$$

The production technology (17) may be used to derive the minimized cost function for each intermediate goods producer:

$$C(q_t, w_t, r_t, X_t, z_t) = \frac{\alpha+\theta}{\alpha}\left[\left(\frac{\alpha}{\theta}\right)^{\theta} q_t\, X_t^{-\alpha}\, w_t^{\alpha}\, r_t^{\theta}\, z_t^{-\varepsilon}\right]^{(\alpha+\theta)^{-1}}$$

In the symmetric equilibrium:

$$Y_t = q_t = F\left[k_t\,, z_t\,, h_t X_t\right] = F\left[\mathbf{K_t^D}\,, \mathbf{Z_t}\,, \mathbf{H_t^D} X_t\right]$$

and $z_t = \mathbf{Z_t}$ so that the this minimized cost function provides the following relationship amongst aggregate variables:

$$\frac{w_t \mathbf{H^D}(w_t, r_t, X_t, Y_t, \mathbf{Z_t})}{r_t \mathbf{K^D}(w_t, r_t, X_t, Y_t, \mathbf{Z_t})} = \frac{\alpha}{\theta} \tag{18}$$

This implies the following expression for the real return on physical capital:

$$r_t = \frac{\theta}{\alpha} \frac{w_t \mathbf{H^D}(w_t, r_t, X_t, Y_t, \mathbf{Z_t})}{\mathbf{K^D}(w_t, r_t, X_t, Y_t, \mathbf{Z_t})}$$

This chapter considers two alternative specifications for the general form of the accumulation technology for organizational capital given by (3). The first specification is the log-linear accumulation technology used by Cooper & Johri (2002) and Johri & Letendre (2002):

$$z_{t+1} = G\left[\, z_t \, , q_t \,\right] = z_t^{\eta} \, q_t^{\gamma} = \mathbf{Z_t}^{\eta} \, \left\{ (\mathbf{K_t^D})^{\theta} \, \mathbf{Z_t}^{\varepsilon} \, (\mathbf{H_t^D} X_t)^{\alpha} \right\}^{\gamma} = \mathbf{Z_{t+1}} \tag{19}$$

with $\eta > 0$ and $\gamma > 0$ where the conditions $q_t = Y_t$ and $z_t = \mathbf{Z_t}$ have been imposed. An alternative specification is the linear accumulation technology. A restricted specification of this linear technology figures prominently in traditional studies of learning-by-doing with a slightly less restricted form studied by Argote et al. (1990) and Benkard (2000):

$$z_{t+1} = G\left[\, z_t \, , q_t \,\right] = \phi_1 \, z_t + \phi_2 \, q_t = \phi_1 \, \mathbf{Z_t} + \phi_2 \, \left\{ \mathbf{K_t^D})^{\theta} \, \mathbf{Z_t}^{\varepsilon} \, (\mathbf{H_t^D} \, X_t)^{\alpha} \right\} = \mathbf{Z_{t+1}} \tag{20}$$

with $\phi_1 > 0$ and $\phi_2 > 0$. The typical study of learning-by-doing (implicitly) imposes the restriction $\phi_1 = \phi_2 = 1$. Alternatively, Argote et al. (1990) and Benkard (2000) restrict $0 < \phi_1 < 1$ and $\phi_2 = 1$.

Using the restrictions implied by a symmetric equilibrium, the expression for the real return on physical capital provided above, and imposing the factor market clearing conditions, the model economy will be characterized by a set of six equations in aggregate variables. From the maximization problem solved by households we obtain:

$$\frac{N}{C_t} - \frac{\Lambda_t^h}{N \, \beta^t} = 0 \tag{21}$$

$$-\frac{\Lambda_t^h}{N \, \beta^t} + \beta \, E_t \left\{ \frac{\Lambda_{t+1}^h}{N \, \beta^{t+1}} \left[\frac{\theta}{\alpha} \, \Phi \, \frac{N \, \beta^{t+1}}{\Lambda_{t+1}^h} \frac{H_{t+1}}{K_{t+1}} + (1 - \delta) \right] \right\} = 0 \tag{22}$$

$$K_t^{\theta} \, Z_t^{\varepsilon} \, (H_t X_t)^{\alpha} + (1 - \delta) K_t - K_{t+1} - C_t - G_t = 0 \tag{23}$$

Since organizational capital is accumulated by the intermediate goods producers, the functional form for the accumulation technology does not alter the first order conditions from the household's problem. When the accumulation technology is characterized by the log-linear form (19), the maximization problem of the intermediate goods producers provides the following first order conditions:

$$K_t^{\theta}\, Z_t^{\varepsilon}\, (H_t X_t)^{\alpha} - \frac{\mu}{\alpha}\,\Phi\,\frac{N\,\beta^t}{\Lambda_t^h}\,H_{t+1} + \gamma\,\mu\,\frac{\Lambda_t^f}{\beta^t}\,Z_{t+1} = 0 \tag{24}$$

$$-\frac{\Lambda_t^f}{\beta^t} + \beta\,E_t\left\{\frac{\varepsilon}{\alpha}\,\Phi\,\frac{N\,\beta^{t+1}}{\Lambda_{t+1}^h}\,\frac{H_{t+1}}{Z_{t+1}} + \eta\,\frac{\Lambda_{t+1}^f}{\beta^{t+1}}\,\frac{Z_{t+1}^{\eta}\,\left\{K_{t+1}^{\theta}\,Z_{t+1}^{\varepsilon}\,(H_{t+1}X_{t+1})^{\alpha}\right\}^{\gamma}}{Z_{t+1}}\right\} = 0 \tag{25}$$

$$Z_{t+1} - Z_t^{\eta}\,\left\{K_t^{\theta}\,Z_t^{\varepsilon}\,(H_t X_t)^{\alpha}\right\}^{\gamma} = 0 \tag{26}$$

Alternatively, when the accumulation technology for organizational capital is characterized by the linear form (20), the maximization problem of the intermediate goods producers provides the following first order conditions:

$$K_t^{\theta}\, Z_t^{\varepsilon}\, (H_t X_t)^{\alpha} - \frac{\mu}{\alpha}\,\Phi\,\frac{N\,\beta^t}{\Lambda_t^h}\,H_{t+1} + \phi_2\,\mu\,\frac{\Lambda_t^f}{\beta^t}\,K_t^{\theta}\,Z_t^{\varepsilon}\,(H_t X_t)^{\alpha} = 0 \tag{27}$$

$$-\frac{\Lambda_t^f}{\beta^t} + \beta\,E_t\left\{\frac{\varepsilon}{\alpha}\,\Phi\,\frac{N\,\beta^{t+1}}{\Lambda_{t+1}^h}\,\frac{H_{t+1}}{Z_{t+1}} + \phi_1\,\frac{\Lambda_{t+1}^f}{\beta^{t+1}}\right\} = 0 \tag{28}$$

$$Z_{t+1} - \phi_1\,Z_t - \phi_2\,\left\{K_t^{\theta}\,Z_t^{\varepsilon}\,(H_t X_t)^{\alpha}\right\} = 0 \tag{29}$$

Finally, it is necessary to close the model by specifying an appropriate law of motion for the level of government consumption. As is common in the literature, this expenditure is modelled as a an exogenous stochastic process, relative to the level of technology and thus introduces a second source of uncertainty into the model. The next section will provide some more detail on the nature of this stochastic process.

2.2.5 A Feasible Steady State

Steady state growth is defined as a situation in which consumption C_t, investment I_t, output Y_t, physical capital K_t, organizational capital Z_t, government consumption G_t, and real wages w_t grow at constant, but possibly differing rates. Since the amount of time devoted to market work must lie between zero and the time endowment T, the only feasible constant growth rate for hours is zero.[11] In order to simplify the analysis, define the quantity $\gamma_M = M_t/M_{t-1}$ so that γ_M will be equal to one plus the growth rate of the variable M. Steady state growth requires that the quantity γ_M be independent of t.

Using the accumulation equation for organizational capital (19), it can be shown that, in the feasible steady state, $\gamma_Z = \gamma_Y^{\gamma/1-\eta}$. When the accumulation technology exhibits constant returns to scale so that $\gamma = 1 - \eta$, the growth rate in output must be equal to the growth rate in organizational capital. For the linear accumulation technology (20) which exhibits (global) constant returns to scale, the growth rate in organizational capital will always be equal to the growth rate in output. Similarly, using the accumulation technology for physical capital, it follows that the growth rate in investment and physical capital must be equal in the steady state.

The aggregate resource constraint is given by $C_t + I_t + G_t = Y_t$. In a steady state, it must be true that γ_C, γ_I, γ_G and γ_Y be independent of t. This requirement will only be satisfied if the share of consumption in total output C_t/Y_t and the share of investment in total output I_t/Y_t are independent of time. However, if the share of consumption in total output is constant, then it follows that consumption C_t and output Y_t are growing at the same rate. Similarly, if the share of investment in total output is constant, then investment I_t and output Y_t must be growing at the same rate. When these shares are constant, the aggregate resource constraint implies that the share of government consumption in total output must also be constant so that government consumption G_t grows at the same rate as output.

The Cobb-Douglas production technology (17) with a constant returns to scale accumulation technology so that $\gamma_K = \gamma_I = \gamma_Y = \gamma_Z$ provides the following:

$$g_Y = \frac{\alpha}{1 - \theta - \varepsilon} g_X$$

[11] King et al. (2002)

where g_M refers to the growth rate of the variable M in the steady state and $g_M(t, t-1) \approx \ln(\gamma_M)$, Only when the production technology exhibits constant returns to scale so that $\alpha+\theta+\varepsilon = 1$ and the accumulation technology exhibits constant returns to scale so that $\eta = \gamma = 1$ will the growth in output be equal to the growth rate in technology. As shown above, when the accumulation technology exhibits constant returns to scale, the ratio of the growth in output relative to the growth rate in technology will only be a function of the production technology parameters. This condition will always be satisfied for the linear accumulation technology which exhibits (global) constant returns to scale. In order to facilitate a comparison to previous research and comparisons between the linear and log-linear accumulation technologies, this chapter will impose constant returns to scale in the log-linear accumulation technology. This ensures that the growth rate in output will always be equal to the growth rate in organization capital in the steady state. Using the expression for g_Y provided above, constant returns to scale in the accumulation technology will also imply that the steady growth rate in output (and organizational capital) for the log-linear technology must be identical to that for the linear accumulation technology.

For the preference relation given by (16), the first order condition for hours (13) from the household problem implies that, in the steady state, the growth rate in real wages will be equal to the growth rate in consumption. Since the growth rate in physical capital is equal to the growth rate in consumption, combined with the requirement that the growth in hours be zero in the steady state, the relationship between real wages and the real return to physical capital (18) implies that the growth rate in the real return to physical capital will be zero in the steady state.

Since the growth rate in technology is stochastic, the growth rates of consumption, investment, physical capital, organizational capital, output and real wages will also be stochastic. In order to eliminate this stochastic component to the growth rates, it is useful to transform the model economy so that the growth rate in all variables is zero. When the accumulation technology exhibits constant returns to scale this transformation involves writing the model in terms of the de-trended variables: $c_t = C_t/X_t^{\chi}$, $i_t = I_t/X_t^{\chi}$, $g_t = G_t/X_t^{\chi}$, $y_t = Y_t/X_t^{\chi}$, $k_t = K_t/X_{t-1}^{\chi}$ and $z_t = Z_t/X_{t-1}^{\chi}$ where $\chi = \alpha/(1-\theta-\varepsilon)$. In addition, define the multipliers $\lambda_t^h = (\Lambda_t^h X_t^{\chi})/(N\beta^t)$ and $\lambda_t^f = \Lambda_t^f/\beta^t$. Note that, in the untransformed model, the steady state growth rate of the household shadow price $\Lambda_t^h/(N\,\beta^t)$ will be given by the negative of the growth rate in output and the plant shadow price Λ_t^f/β^t will not grow in the (untransformed) steady state.[12] In this transformed economy, government consumption is assumed to evolve according to the following stochastic process:

$$\ln g_t = \ln G_t - \chi\,\ln X_t = (1-\rho_g)\,\ln \bar{g} + \rho_g\,\ln g_{t-1} + \zeta_{gt}$$

where $|\rho_g| < 1$, $\ln \bar{g}$ is the mean of $\ln g_t$ and ζ_{gt} is a serially uncorrelated process with mean 0 and standard deviation $\sigma_{\zeta g}$. By definition, the level of untransformed government consumption G_t is determined by both the transformed level of government consumption g_t and the level of technology X_t. Since the level of technology is assumed to follow a random walk with drift, movements in the level of technology have a permanent impact upon the level of government consumption G_t whilst movements in g_t have a transitory impact upon the level of government consumption. This specification for the law of motion for exogenous government consumption represents the simplest stochastic process that allows for persistence in the level of government consumption. It is quite standard and features prominently in existing dynamic general equilibrium models such as Christiano & Eichenbaum (1992), Burnside & Eichenbaum (1996), Devereux et al. (1996) and Guo (2004).

When the accumulation technology is characterized by a log-linear technology of the form (19), the transformed economy will be characterized by the following equations:

$$\frac{N}{c_t} - \lambda_t^h = 0 \tag{30}$$

$$-\lambda_t^h + \beta E_t \left\{ \lambda_{t+1}^h \left[\frac{\theta}{\alpha}\,\frac{H_{t+1}}{k_{t+1}}\,\frac{\Phi}{\lambda_{t+1}^h} + \exp\left[-\chi(\psi_x + \zeta_{t+1})\right]\,(1-\delta) \right] \right\} = 0 \tag{31}$$

$$y_t + \exp\left[-\chi(\psi_x + \zeta_t)\right]\,(1-\delta)\,k_t - k_{t+1} - c_t - g_t = 0 \tag{32}$$

[12]Since the structural model outlined above is essentially a model of (production) plant behaviour, rather than a model of firm behaviour, for the remainder of this thesis, the terms plant, production unit, and intermediate goods producer will have the same interpretation.

$$y_t - \frac{\mu}{\alpha}\frac{\Phi}{\lambda_t^h} H_t + \gamma\,\mu\,\lambda_t^f\, z_{t+1} = 0 \tag{33}$$

$$-\lambda_t^f + \beta E_t \left\{ \exp\left[\chi(\psi_x + \zeta_{t+1})\right] \left[\frac{\varepsilon}{\alpha}\frac{\Phi}{\lambda_{t+1}^h}\frac{H_{t+1}}{z_{t+1}} + \eta\,\lambda_{t+1}^f\,\frac{z_{t+2}}{z_{t+1}}\right]\right\} = 0 \tag{34}$$

$$z_{t+1} - \exp\left[-\chi(\eta + \varepsilon\gamma + \theta\gamma)(\psi_x + \zeta_t)\right]\, z_t^{\eta+\varepsilon\gamma}\, k_t^{\theta\gamma}\, H_t^{\alpha\gamma} = 0 \tag{35}$$

$$y_t - H_t^{\alpha}\, k_t^{\theta}\, z_t^{\varepsilon}\, \exp\left[-\chi(\theta + \varepsilon)(\psi_x + \zeta_t)\right] = 0 \tag{36}$$

$$\ln g_t = (1 - \rho_g)\, \ln \bar{g} + \rho_g\, \ln g_{t-1} + \zeta_{gt} \tag{37}$$

Alternatively, when the accumulation technology is characterized by a linear technology of the form (20), the production side of the model will be characterized by the following equations:

$$H_t^{\alpha}\, k_t^{\theta}\, z_t^{\varepsilon}\, \exp\left[-\chi(\theta + \varepsilon)(\psi_x + \zeta_t)\right]\left\{1 + \lambda_t^f\,\mu\,\phi_2\right\} - \frac{\mu}{\alpha}\frac{\Phi}{\lambda_t^h} H_t = 0 \tag{38}$$

$$-\lambda_t^f + \beta E_t \left\{\frac{\varepsilon}{\alpha}\frac{\Phi}{\lambda_{t+1}^h}\frac{H_{t+1}}{z_{t+1}} \exp\left[\chi(\psi_x + \zeta_{t+1})\right] + \lambda_{t+1}^f\,\phi_1\right\} = 0 \tag{39}$$

$$z_{t+1} - \phi_1\, z_t\, \exp\left[-\chi(\psi_x + \zeta_t)\right] - \phi_2\, H_t^{\alpha}\, k_t^{\theta}\, z_t^{\varepsilon}\, \exp\left[-\chi(\theta + \varepsilon)(\psi_x + \zeta_t)\right] = 0 \tag{40}$$

2.3 The Non-Stochastic Steady State

Appendix A.2 presents some expressions for key variables in the non-stochastic steady state of this transformed economy, after imposing constant returns to scale in the accumulation technology. It is clear that both the productivity of organizational capital and the parameters of the accumulation technology affect these key variables in the non-stochastic steady state, particularly, the steady state k/y ratio, the steady state factor revenue shares, and the steady state markup.

Prior to studying the properties of this non-stochastic steady state, it is worthwhile considering whether there are additional parameter restrictions that should be imposed upon this non-stochastic steady state, beyond the parameter restrictions identified above.

2.3.1 Required Parameter Restrictions

An examination of Appendix A.2 reveals a term that is common to the labour share, physical capital share, the markup and the k/y ratio for the model with a log-linear accumulation technology. This term is given by:

$$\frac{1-\beta\exp(\chi\psi_x)(1-\gamma)}{1-\beta\exp(\chi\psi_x)\left[1-\gamma(1-\varepsilon)\right]} = \frac{1-\beta\exp(\chi\psi_x)(1-\gamma)}{1-\beta\exp(\chi\psi_x)(1-\gamma)-\beta\exp(\chi\psi_x)\gamma\varepsilon}$$

This common term will need to exceed zero for the steady state k/y to be well defined. The denominator in the above expression will always be less than the numerator, in absolute value. This implies the restriction that the denominator be greater than zero will also restrict the numerator to be greater than zero and this common term will exceed zero. Similarly, if the numerator were less than zero, the denominator would also be less than zero such that the common term would exceed zero. Therefore, it is necessary to restrict the magnitude of the term $\beta\exp(\chi\psi_x)\gamma\varepsilon$ so that the case where the numerator is positive (negative) and the denominator is negative (positive) cannot arise. Formally this restriction will take the form:

$$1-\beta\exp(\chi\psi_x)(1-\gamma) > \beta\exp(\chi\psi_x)\gamma\varepsilon$$

Similarly, this common term for the linear technology will be given by:

$$\frac{1-\beta\phi_1}{1-\beta\phi_1+\beta\varepsilon\phi_1-\beta\varepsilon\exp(\chi\psi_x)} = \frac{1-\beta\phi_1}{1-\beta\phi_1-\beta\varepsilon[\exp(\chi\psi_x)-\phi_1]}$$

Once again the denominator in the above expression will always be less than (or equal to) the numerator, in absolute value, given the restriction $\exp(\chi\psi_x)-\phi_1 \geq 0$. Consider the alternative where this restriction does not hold. Using the expression for the z/y in the non-stochastic steady state, the restriction $\exp(\chi\psi_x) - \phi_1 < 0$ would imply a negative value for z/y, which is clearly unreasonable. In addition, it will be necessary to impose the following restriction:

$$1 - \beta\phi_1 > \beta\varepsilon[\exp(\chi\psi_x) - \phi_1]$$

Note that these restrictions, which guarantee the common terms for the economy characterized by either with a log-linear accumulation technology or a linear technology exceed zero also impose some restrictions on appropriate values for the demand parameter μ. For example, consider the case where both the numerator and the denominator in the common term for the log-linear technology, are greater than zero. This implies that the bracketed term in the expression for the markup presented in Appendix A.2 might be less than one so that the steady state markup might be less than one for a value of the demand parameter μ sufficiently close to unity. This problem will not arise when both the numerator and the denominator in the common terms are less than zero.

As discussed below, the calibrated values for the organizational capital parameters, the discount rate, the production technology parameters, and the mean growth rate in output, which are consistent with either the microeconomic data or the data for the aggregate economy, imply that both the numerator and the denominator in these common terns are greater than zero. This suggests that the restriction on the demand parameter, identified above, might be particularly binding.

It is necessary to impose some further restrictions upon the parameters of the linear accumulation technology. The linear accumulation technology may be written in the following form:

$$Z_t = \phi_1^t \, Z_0 + \phi_2 \sum_{j=0}^{t-2} \phi_1^j \, Y_{t-1-j}$$

It is clear that the (aggregate) stock of organizational capital will not be well defined for values of $\phi_1 > 1$ since the stock of organizational capital will explode regardless of the value of ϕ_2. For this reason, it will be assumed that the restriction $0 < \phi_1 \leq 1$ is satisfied. However, a value of $\phi_1 = 1$ cannot be supported as a steady state since the value of z/y will become extremely large and in the case where $\psi_x = 0$ this ratio will be infinitely large. This is particularly important since the traditional studies of learning-by-doing impose the restriction $\phi_1 = 1$. Intuitively, when the parameter ϕ_1 is interpreted as a "depreciation" rate of organizational capital, this interpretation only makes sense when $0 < \phi_1 < 1$. In this case, the restriction $\exp(\chi\psi_x) - \phi_1 > 0$ will always be satisfied.

In the linear technology, the parameter ϕ_2 represents the contribution of investment in organizational capital to the stock of organizational capital. As such, the case where $\phi_2 > 1$ so that a unit of investment in organizational capital produces more than a unit of organizational capital is difficult to motivate. For this reason, the restriction $\phi_2 \leq 1$ will be imposed.

There is an additional parameter restriction that will need to be imposed based upon the sufficient condition for profit maximization. Using the expression for output provided in Appendix A.2, this requires that the restriction $(\alpha + \theta)/[\mu(1 - \varepsilon)] \leq 1$ be satisfied.

2.3.2 Steady State Comparative Statics

After imposing the parameter restrictions above, it is useful to consider the impact upon the key variables in the non-stochastic steady state of varying either the productivity of organizational capital controlled by ε or the accumulation technology parameters. For example, this exercise involves comparing a non-stochastic steady state characterized by a value of ε_0 to an alternative non-stochastic steady state characterized by a different value of ε.

There are two ways in which the value of ε affects the values of the key aggregate variables presented in Appendix A.2. Firstly there will be a direct effect of ε upon these key variables. However, there will also be an indirect effect that alters the magnitude of the term $\chi\psi_x$. This is because the parameter χ depends upon the value of ε.

It is worthwhile to consider further the parameter χ. The expression for the (steady state) growth rate in output, provided above, is given by

$$g_Y = \theta\, g_K + \alpha\, g_H + \varepsilon\, g_Z + \alpha\, g_X$$

so that the (steady state) growth rate in output is determined by the (exogenous) growth in the level of technology and the growth rates in the productive inputs. By definition, the presence of increasing returns to scale implies that a proportionate increase in the quantities of the factor inputs will produce a more than proportionate increase in the level of output. Alternatively, in the case of constant returns to scale, the growth rate in output, net of the growth in productive inputs will given by the growth rate in technology. Therefore, the term χ must represent some form of scale effect—with increasing returns to scale, the growth rate in output, net of the growth in productive inputs must exceed the growth in technology. Fundamentally, the value of χ, which affects the growth rate in output, affects the transformation necessary to produce a zero growth rate in output in the transformed economy.

Of course, it is inappropriate to conclude that since the indirect effect reflects the impact of alternative values of ε upon the scale elasticity, the direct effect reflects the impact of alternative values of ε, independent of this scale effect. For the moment consider that this conclusion is made. This would imply that the scale effect could be removed by simply assuming that $\psi_x = 0$. Generally, the direct effect reflects that fact that variations in the value of ε, affect *both* the productivity of organizational capital (and the scale elasticity) and the accumulation of organizational capital such that it is not possible to study this productivity of organizational capital, independently of accumulation.

Despite this, in order to understand the importance of these two effects, it is useful to (initially) ignore that fact that χ is a function of ε and restrict attention to the case where only the direct effect is present.

Concentrating upon the expressions for the log-linear accumulation technology presented in Appendix A.2, it can be shown that the share of labour in total revenue (A.2.9), the share of physical capital in total revenue (A.2.10), and the k/y ratio (A.2.12) are all increasing in the value of ε. The steady state markup (A.2.11) will be decreasing in the value of ε. The steady state share of physical capital investment in total output will need to be increasing in the value of ε in order to generate the larger k/y ratio. Provided the share of government consumption in output is independent of ε, the share of consumption in total output will be decreasing in the value of ε. These results will also apply to the linear accumulation technology.

It is worth noting that the value of ε has no direct effect upon the value of z/y in the non-stochastic steady state. This result holds for both the log-linear and the linear accumulation technologies. Intuitively, this reflects the restriction that the steady state growth rate of output be identical to the growth rate in organizational capital in the feasible steady state of the untransformed model.

Consider the impact of relaxing the requirement that $\chi\psi_x$ be independent of ε. Since the term χ will be increasing in the value of ε, for given values of (α, θ, ψ_x), it can be shown that the share of labour in total revenues and the share of physical capital in total revenues will be increasing in the term $\chi\psi_x$. When $\varepsilon_1 > \varepsilon_0$, the steady state associated with the value of ε_1 will be characterized by a larger revenue share of labour and a larger revenue share of physical capital arising from both the direct effect and the indirect effect operating through the term $(\chi\psi_x)$. The indirect effect *reinforces* the direct effect. Similarly, the steady state markup will be lower due to both the direct effect and the indirect effect.

The indirect effect has a somewhat more complicated impact upon the steady state k/y ratio. This can be seen be expressing the physical capital share as:

$$ksh = r_k \frac{k}{y} \qquad \text{with} \qquad r_k = \frac{\exp(\chi\psi_x)}{\beta} - (1-\delta)$$

where r_k represents the real rental price of physical capital in the non-stochastic steady state. Thus:

$$\frac{\partial(ksh)}{\partial\varepsilon} = r_k \frac{\partial(k/y)}{\partial\varepsilon} + \frac{k}{y}\frac{\partial r_k}{\partial\varepsilon}$$

It has already been stated above that this entire expression will be increasing in the value of ε. The first effect is the impact of ε upon the physical capital share, holding the rental price constant and the second effect is the impact upon the physical capital share, holding the k/y ratio constant. Since the physical capital share is an identity, only two of these three derivatives may be calculated independently. Consequently, it is possible to write this expression as:

$$\frac{\partial(k/y)}{\partial\varepsilon} = \frac{1}{r_k}\frac{\partial ksh}{\partial\varepsilon} - \frac{(k/y)}{r_k}\frac{\partial r_k}{\partial\varepsilon}$$

Since both of the partial derivatives on the right hand side are positive, the net effect of larger values of ε upon the steady state k/y ratio will be ambiguous. In particular, for specific parameter values, a larger value of ε might be associated with a lower k/y ratio.

As noted above, there is no direct effect upon the steady state z/y ratio. However, the indirect effect of a larger value of χ associated with a larger value of ε reduces the steady state z/y ratio. This simply reflects the fact that a larger value of ε raises the term χ which affects the transformation needed to generate a zero growth rate in all variables.

When the accumulation technology is characterized by constant returns to scale, the term χ will not depend upon the accumulation technology parameters so that only a direct effect will need to be considered when comparing steady states with differing values for the accumulation technology parameters. Concentrating upon the log-linear accumulation technology, the revenue share of labour and the revenue share of physical capital will be increasing in γ and the markup decreasing in γ provided the restriction $\beta \exp(\chi\psi_x) < 1$ is satisfied. In this case, both the k/y ratio and the z/y ratio will be increasing in γ. The steady state share of physical capital investment in total output will need to be increasing in the value of γ in order to generate the larger k/y ratio. Provided the share of government consumption in output is independent of γ, the share of consumption in total output will be decreasing in the value of γ.

These qualitative results will hold for the linear accumulation technology provided the restriction $\beta \exp(\chi\psi_x) > 1$ is satisfied. Note that this restriction has the opposite sign to the restriction required for the log-linear technology. This is because ϕ_1, which parameterizes the contribution of the existing capital stock to the future stock of organizational capital, should be compared to η for the log-linear technology. With constant returns to scale, the parameter η can only be increased by reducing the magnitude of γ. For the linear accumulation technology, the steady state z/y will also depend upon ϕ_2 which parameterizes the contribution of current period output to next period's stock of organizational capital. In particular, larger values of ϕ_2 will be associated with steady states with a larger z/y ratio.

Appendix A.2 also presents expressions for some key macroeconomic variables in an otherwise identical structural model that ignores the accumulation of organizational capital. By comparing these expressions with those for the structural model of organizational capital, it is possible to establish the steady state implications of ignoring the accumulation of organizational capital. Since the accumulation of organizational capital significantly alters the first order conditions associated with the production unit's maximization problem, these expressions for this simple model cannot be derived by simply assuming that organizational capital is unproductive (i.e. $\varepsilon = 0$).

For given values of α, θ, μ it is possible to express the steady state expressions for this organizational capital model, in terms of the equivalent expression for the model that ignores organizational capital. This is complicated by the fact that the term χ for this simple model will always be lower than that associated with the organizational capital model, primarily because for given values of α and θ, the accumulation of organizational capital will raise the returns to scale of the production technology. However, since χ only appears in the term $\exp(\chi\psi_x)$, any difference between the term $\exp(\chi_0\psi_x)$ for the simple model and $\exp(\chi\psi_x)$ for the organizational capital model is likely to be quite small for reasonable values for both ψ_x and ε.[13]

Concentrating upon the log-linear accumulation technology, the factor revenue shares for the organizational capital model may be expressed as:

$$lsh = lsh_0 \left\{ \frac{1 - \beta\exp(\chi\psi_x)(1-\gamma)}{1 - \beta\exp(\chi\psi_x)\left[1 - \gamma(1-\varepsilon)\right]} \right\}$$

and

$$ksh = ksh_0 \frac{\exp(\chi\psi_x)}{\exp(\chi_0\psi_x)} \left\{ \frac{1 - \beta\exp(\chi\psi_x)(1-\gamma)}{1 - \beta\exp(\chi\psi_x)\left[1 - \gamma(1-\varepsilon)\right]} \right\}$$

For the required parameter restrictions outlined above, the bracketed term will be greater than unity. In addition, for a given value of ψ_x, it will be true that $\exp(\chi\psi_x) > \exp(\chi_0\psi_x)$ so that both the labour share and the physical capital share must be larger, allowing for the accumulation of organizational capital. Similarly,

$$markup = markup_0 \left\{ \frac{1 - \beta\exp(\chi\psi_x)\left[1 - \gamma(1-\varepsilon)\right]}{1 - \beta\exp(\chi\psi_x)(1-\gamma)} \right\}$$

which implies that the steady state markup in the model with organizational capital

[13] Magnitudes for the model that ignores organizational capital are represented by a zero subscript.

will be lower than the markup in the simple model. Fundamentally, this lower steady state markup reflects the dynamic structure associated with the accumulation of organizational capital. Firstly, there will be a particular output price associated with the level of output in the non-stochastic steady state. However, as shown in Appendix A.2, the stock of organizational capital will be proportional to this level of output so that this steady state output price must be such that it delivers the appropriate steady state stock of organizational capital. This suggests that the accumulation of organizational capital produces an additional constraint upon the steady state output price that does not appear in the simple model. Of course, the markup also depends upon the level of marginal costs in the steady state, which will depend upon the steady state real wage, real rental price of physical capital, and the level of output. The net effect of the accumulation of organizational capital upon both the steady state output price and the marginal costs will be reflected in the steady state markup.

The k/y ratio in the non-stochastic steady state may be written as:

$$\frac{k}{y} = \left[\frac{k}{y}\right]_0 \frac{1-\beta\exp(-\chi_0\psi_x)(1-\delta)}{1-\beta\exp(-\chi\psi_x)(1-\delta)} \left\{\frac{1-\beta\exp(\chi\psi_x)(1-\gamma)}{1-\beta\exp(\chi\psi_x)\left[1-\gamma(1-\varepsilon)\right]}\right\}$$

For the particular values for the structural parameters considered in this thesis, the k/y ratio in the non-stochastic steady state of the organizational capital will exceed that in the model that ignores organizational capital. Since k/y exceeds $(k/y)_0$, it will also be true that $i/y > (i/y)_0$ in order to support the larger steady state k/y ratio. Similarly, for a given share of government consumption g/y, it must be true that $c/y < (c/y)_0$.

These comparative statics exercises have shown that the particular values for the structural parameters, and in particular the organizational capital parameters may considerably alter the value of some key macroeconomic variables in the non-stochastic state.

2.3.3 Comparison to Previous Research

In order to further understand the particular decentralization presented in this thesis, it useful to compare the k/y ratio provided in Appendix A.2 with that implied by both the Chang et al. (2002) model and the planning solution of Cooper & Johri

(2002).

The planning solution of Cooper & Johri (2002) implies the following k/y ratio in the non-stochastic steady state

$$\frac{\bar{k}}{\bar{y}} = \theta \frac{\beta}{1-\beta\exp(-\chi\psi_x)(1-\delta)} \left\{ \frac{1-\beta(1-\gamma)}{1-\beta[1-\gamma(1-\varepsilon)]} \right\}$$

Alternatively, the model of Chang et al. (2002) implies the following k/y ratio in the non-stochastic steady state

$$\frac{\bar{k}}{\bar{y}} = \theta \frac{\beta}{1-\beta\exp(-\chi\psi_x)(1-\delta)}$$

which will be identical to the k/y ratio in the standard neoclassical stochastic growth model. This implies that the accumulation of production experience by households has no effect upon the steady state k/y ratio. It is clear that the k/y ratio in the Cooper & Johri (2002) model will exceed that in the Chang et al. (2002) model.

Intuitively, the difference between these two expressions for the steady state k/y reflects a differing Euler equation for physical capital arising from a different representation of the accumulation of experience. In both models, the first order condition for physical capital implies that the utility cost of giving up one unit of consumption in the current period will be equated to the present value (in terms of utility) of this additional unit of consumption in the following period. However, the particular interpretation of production experience affects this (future) value of postponing consumption. In the model of Chang et al. (2002), investment in physical capital has no impact upon the stock of experience so that the (future) value of postponing consumption has the same interpretation as that in the standard neoclassical model. In contrast, the model of Cooper & Johri (2002) implies that an additional unit of physical capital produces production experience so that the future benefit will include a term reflecting the future marginal utility of the additional output produced arising from the subsequently larger stock of organizational capital.

It is also possible to compare the expression for the steady state k/y, provided in Appendix A.2, with the expression for the steady state k/y in Cooper & Johri

(2002). Assuming the parameters θ, β, $\chi\psi_x$ are the same:

$$\frac{k}{y} = \left[\frac{k}{y}\right]^{SP} \frac{1}{\mu} \left[\left\{ \frac{1-\beta(1-\gamma)}{1-\beta[1-\gamma(1-\varepsilon)]} \right\}^{-1} \left\{ \frac{1-\beta\exp(\chi\psi_x)(1-\gamma)}{1-\beta\exp(\chi\psi_x)[1-\gamma(1-\varepsilon)]} \right\} \right]$$

where the term $(k/y)^{SP}$ refers to the k/y ratio from the Cooper & Johri (2002) model. It can be seen that the k/y ratio in the structural model presented above will differ from that implied by the planning solution of Cooper & Johri (2002) for two reasons. Firstly, for a given value of μ, the term in square brackets will exceed unity such that k/y will exceed k/y^{SP}. However, larger values of μ will be associated with a k/y ratio for the decentralized model, that is lower than that associated with the planning solution. This is because production units face a demand constraint which drives a wedge between the equilibrium (market) prices in the decentralized model and the shadow prices in the planner's problem. The interaction of these two effects will determine the size of k/y, relative to k/y^{SP}.

The term in square brackets reflects the different valuation placed on a unit of organizational capital in the planner's problem, compared to the decentralized problem outlined above. The value of an additional unit of organizational capital to the planner is measured in terms of the marginal utility of consumption. The steady state growth rate in this shadow price will given by the negative growth rate of output. Therefore, in the transformed economy, it will be necessary to deflate this growth in the value of an additional unit of organizational capital. In contrast, in the structural model outlined above, the value of an additional unit of organizational capital is measured in terms of marginal profit. It has been shown above that this value of an additional unit of organizational capital, measured by the plant multiplier λ^f will not be growing in the steady state. As such it will not be necessary to deflate this multiplier in the transformed economy.

Note that for reasonable values for the growth rate in output, this term in square brackets will be quite close to unity. In this case, the k/y associated with the structural model of organizational capital outlined above, will be considerably lower than that associated with the planning solution. This arises because the demand parameter μ exceeds unity.

2.4 Calibration of the Structural Model

The comparative statics exercises outlined above have established, at least qualitatively, some effects upon the non-stochastic steady state of allowing for the accumulation of organizational capital. Beyond these simple comparative statics exercises, the ability to explore particular features of the structural model is limited without knowledge of the values for the individual structural parameters. Although this chapter only considers the properties of the non-stochastic steady state, it is useful to outline a strategy for assigning values to the structural parameters, which may be used to study the transitional dynamics of the structural model in the next chapter. Wherever possible, these values will be chosen based upon the microeconomic evidence and the macroeconomic data so that the magnitude of key variables in the non-stochastic steady state will be consistent with the macroeconomic data.

Ideally, these values for the structural parameters would be obtained from estimation of the full structural model. However, for the linear accumulation technology, this would require knowledge of the time series for the (unobservable) stock of organizational capital. An alternative strategy, which does not require a time series for the stock of organizational capital, would involve calibrating the values of these parameters to reasonable values from existing microeconomic studies and the macroeconomic data so that the key variables in the non-stochastic steady state are consistent with the time series averages from the macroeconomic data. It will be necessary to assign values for the production technology parameters (α, θ and ε), the accumulation technology parameters (η, γ) the demand parameter (μ), the discount rate (β), the depreciation rate of physical capital (δ), the growth rate in the level of technology (ψ_x), the output share of government consumption in the non-stochastic steady state (g/y), and the preference parameter (Φ).

An examination of Appendix A.2 reveals that the expressions for some of the key variables in the non-stochastic steady state will depend upon a (non-linear) function of the term $\chi\psi_x$. Since the term χ depends upon the values of the individual production technology parameters, these key variables will be a non-linear function of the individual production technology parameters. The calibration of the model could be greatly simplified if these key variables, in the non-stochastic steady state, could be assumed to not depend upon this non-linear function of the individual production technology parameters. This might arise in several situations.

The first case arises when the value of the growth rate in the level of technology is zero. In this case the term $\chi\psi_x = 0$. In addition, when the parameters of the (constant returns) log-linear accumulation technology are identical to the parameters of the linear accumulation technology so that $1-\gamma = \phi_1$ and $\gamma = \phi_2$, the magnitude of key variables in the non-stochastic steady state will be identical for both the log-linear and the linear accumulation technologies with the ratio $z/y = 1$ in the non-stochastic steady state. Since it is standard in the business cycle literature to allow for a non-zero growth rate in the level of technology, the restriction $\psi_x = 0$ will not be imposed. This will allow a comparison to existing models of economic fluctuations, particularly with respect to the transitional dynamics of the structural model.

A second case arises when the production technology exhibits constant returns to scale. In this case, the term $\chi = 1$. The structural model includes a monopolistically competitive output market primarily to allow for a decentralized equilibrium in the presence of an increasing returns to scale production technology. However, when $\chi = 1$, a decentralized equilibrium might just as easily be supported by the simpler assumption of perfect competition.

The assumption of a constant returns to scale production technology implies not only that average costs of production will be identical to marginal costs of production but also that these average costs of production will be independent of output. Since the stock of organizational capital in the non-stochastic steady state will be proportional to the level of output in the non-stochastic steady state, this implies that average (and marginal) costs of production must be independent of the stock of organizational capital. This implies that there can be no economies of scale in the non-stochastic steady state associated with the accumulation of organizational capital. Although, the structural model does not necessarily require the existence of these economies of scale in the non-stochastic steady state, the assumption that $\chi = 1$, which precludes the existence of any economies of scale, seems overly restrictive. Consequently, it would be preferable to allow the parameter χ to take on values that satisfy $\chi \geq 1$.

The final case arises when the term $(\chi\psi_x)$ is independent of the production technology parameters. Since the term χ depends on the values of α, θ and ε this could be achieved by making the growth rate in the level of technology also a function of these production technology parameters. The assumption is that steady states with different values of α, θ and ε would also be characterized by a different mean growth rate in the level of technology such that the mean growth in output $(\chi\psi_x)$ is the same. Since the term χ will be an increasing function of α, θ and ε, this requires that steady states with larger values of α, θ and ε are characterized by a lower mean growth rate in the level of technology.

This assumption is seen as the simplest assumption that will allow for a non-zero growth rate in the level of technology ψ_x and allow for increasing returns to scale $(\chi > 1)$ at the same time ensuring that the key variables in the non-stochastic steady state do not depend upon a non-linear function of the production technology parameters. This will make the calibration of the structural model much easier.

This assumption is not entirely unrealistic. In the standard business cycle model with a constant returns to scale production technology, the mean growth rate of output will be given by the mean growth in the level of technology. It is the assumption of a constant returns to scale production technology that allows the unobservable parameter ψ_x to be set using the (observable) mean growth rate in output. This is equivalent to the approach outlined above such that the unobservable term $(\chi\psi_x)$ is tied down using the (observable) mean growth in output. However, the difference is that values of $\chi > 1$ will be associated with a lower mean growth in the level of technology. Since values of $\chi > 1$ require a production technology that exhibits increasing returns to scale, this assumption simply suggests that the presence of increasing returns to scale alters that part of the growth in output that may be attributed to (exogenous) technical progress.

Note that this assumption will remove the indirect effect, identified above, associated with steady states characterized by alternative values of ε. Importantly, since the term $(\chi\psi_x)$ will be assumed to be independent of the value of ε, the steady state rental price of physical capital will also be independent of ε. This implies that larger values of ε will be associated with a larger k/y ratio.

Since the term $(\chi\psi_x)$ measures the mean growth rate of output in the untransformed model, it may be chosen to match the mean growth of output in the data. There is somewhat of a consensus that this growth rate is approximately 1.6% per year which implies a mean growth rate of 0.04% per quarter. This is the figure used by both Christiano & Eichenbaum (1992) and King & Rebelo (1999).

As presented above, the accumulation of organizational capital affects the technology of the (representative) production unit. Consequently, it seems appropriate to assume that the demand parameter μ is not affected by the accumulation of organizational capital. In the standard model of monopolistic competition, the demand parameter will be equivalent to the markup. With a zero profit condition so that production units cannot earn monopoly rents, the demand parameter will also reflect the returns to scale of the production technology. This suggests that the value of μ might be chosen to match estimates of the aggregate degree of returns to scale.

Previous attempts to measure the degree of returns to scale using instrumental variable techniques have yielded quite a range of estimates often with large standard errors. Despite this, the consensus view based upon the work of Basu (1996) and Basu & Fernald (1997) is that the scale elasticity measured by $(\alpha + \theta)$ is close to unity. Consistent with this consensus view, Chari et al. (2000) calibrate their model with a value of $\mu = 1.1$. With a zero profit condition this implies a scale elasticity of $rts = \mu = 1.1$.

This strategy for calibrating the value of μ would be inappropriate for several reasons. Firstly, when production units accumulate organizational capital, these estimates of returns to scale based upon models that do not allow for the accumulation of organizational are likely to be biased. Since the accumulation of organizational capital might raise the plant level returns to scale, existing estimates of the returns to scale are likely to underestimate the true returns to scale.[14] This suggests that a value of $\mu = 1.1$, which is based upon these scale estimates, would no longer be appropriate.

Secondly, the accumulation of organizational capital alters the nature of the relationship between the scale elasticity, the steady state markup and the demand parameter μ. As shown by Hall (1990), the scale elasticity of the production technology, the markup of output price over marginal cost and the sum of the factor revenue

[14]Since the stock of organizational capital will be correlated with the physical capital and labour inputs, this represents a form of omitted variable bias.

shares will be related according to the following:

$$rts = \frac{AC}{MC} = \frac{\partial y}{\partial k}\frac{k}{y} + \frac{\partial y}{\partial h}\frac{h}{y} = \frac{1}{1-\varepsilon}\frac{v}{PMC}\left[\frac{P\,w\,h}{v\,y} + \frac{P\,r\,k}{v\,y}\exp(-\chi\psi_x)\right]$$

It is clear that, even when the factor revenue shares sum to unity, the steady state markup will differ from the scale elasticity by the factor $(1-\varepsilon)^{-1}$.

In addition, the relationship between the markup and the demand parameter μ can be seen by studying the expression for the markup provided in Appendix A.2. For the log-linear accumulation technology, the markup will be given by

$$markup = \frac{v}{PMC} = \frac{rts(1-\varepsilon)}{lsh + ksh\exp(-\chi\psi_x)} = \mu\left\{\frac{1-\beta\exp(\chi\psi_x)(1-\gamma+\gamma\varepsilon)}{1-\beta\exp(\chi\psi_x)(1-\gamma)}\right\}$$

Similarly for the linear accumulation technology:

$$markup = \frac{v}{PMC} = \frac{rts(1-\varepsilon)}{lsh + ksh\exp(-\chi\psi_x)} = \mu\left\{\frac{1-\beta\phi_1+\beta\varepsilon\phi_1-\beta\varepsilon\exp(\chi\psi_x)}{1-\beta\phi_1}\right\}$$

where *markup* refers to the (steady state) markup of output price over marginal cost, *lsh* refers to the (steady state) share of payments to labour in total revenues and *ksh* refers to the (steady state) share of rental payments to owners of physical capital in total revenues. It is clear from the above expressions that the demand parameter μ will no longer be equivalent to the steady state markup. For this reason, it is inappropriate to calibrate the demand parameter μ to match estimates from existing studies. An alternative method for determining the value of the demand parameter will need to be used. Technically, for a given value of μ, reasonable values for ε, $(\chi\psi_x)$, β, and $\gamma = 1-\phi_1$ might be associated with a steady state markup less than one.

Despite these problems in determining an appropriate value for μ based upon the existing estimates, it can be seen that if the term $[lsh + ksh\exp(-\chi\psi_x)]$ could somehow be determined from the data, the markup might be calculated using knowledge of the sum $(\alpha+\theta)$ which may or may not coincide with the scale elasticity of the simple model with monopolistic competition. This is the strategy that will used to calculate the markup and consequently the demand parameter μ.

The term $1-[lsh+ksh\exp(-\chi\psi_x)]$ will represent the (residual) share of profits in total revenues. Note that the structural model restricts the number of intermediate goods producers to be fixed in every period. Since the structural model contains no explicit barriers to entry, this will be consistent with these producers operating in every period if profits in the steady state are zero so that there is no permanent entry or exit. It is important to emphasize that such a zero profit condition restricts pure profits to be zero in the steady state. In a model without the accumulation of organizational capital, the rate of pure profit would be restricted so that the (symmetric) production units cannot earn monopoly rents in the steady state.

However, in the model that allows for the accumulation of organizational capital, the rate of pure profit will not necessarily coincide with the rate of residual profit, net of the share of revenues paid to the owners of labour and physical capital. The residual profit share will include both rates of pure profit associated with monopoly rents and payments to the owners of organizational capital. In this case, the implementation of a zero profit condition becomes somewhat more complicated. The appropriate zero profit condition would restrict rates of pure profit to be zero so that production units cannot earn positive monopoly rents. In this case, any monopoly rents would be distributed to the owners of labour, physical capital and organizational capital. However, when payments to owners of organizational capital are not shared with the owners of labour and physical capital, a non-zero residual profit share might be consistent with the absence of monopoly rents. In particular, the appropriate zero profit condition would impose that payments to the owners of labour, physical capital and organizational capital sum to unity. This would not be equivalent to the restriction $1-[lsh+ksh\exp(-\chi\psi_x)]=0$.

It is clear from Appendix A.2 that the steady state labour share for the model with organizational capital is different than that implied by a model that ignores organizational capital. However, it would be incorrect to assume that this difference reflects payments to the owners of organizational capital that are shared with workers. Specifically this difference reflects the different steady state labour input, stock of organizational capital and output, associated with the accumulation of organizational capital, that affect the steady state real wage and rental price of physical capital.

The structural model in its present form is not suitable for identifying that portion of the residual profit share that reflects pure profit and that portion that reflects payments to the owners of organizational capital. One possible solution is to postulate several alternative values for the residual profit share in the non-stochastic steady state which reflect both rates of pure profit and payments to the owners of physical capital. Using data from the national accounts over the period 1959–1999, Atkeson & Kehoe (2002) report a (mean) residual profit share of 9% of total manufacturing output. They suggest that approximately 4% of manufacturing output might be reasonably attributed to payments to the owners of organizational capital. Consistent with the results of Atkeson & Kehoe (2002), several values for the residual profit share will be used—10%, 5% and 1%. These alternative residual profit shares will be specified independently of the production technology and accumulation technology parameters. As stated above, the bracketed terms in the labour share (A.2.9) or (A.2.17) and physical capital share (A.2.10) or (A.2.18) will be increasing in the value of ε and γ so that, in order to keep the residual profit share fixed, alternative values for the organizational capital parameters must be reflected in alternative values for α, θ or μ. Intuitively, variations in the organizational capital parameters affect the magnitude of the payments to the owners of organizational capital. With a fixed residual profit share, variations in these organizational capital parameters must also affect that portion of the residual profit share that reflects monopoly rents, which is controlled by the demand parameter μ.

The critical advantage of specifying alternative values for the residual profit share is that the steady state markup may then be determined for alternative values for the sum $(\alpha + \theta)$. Generally, it would be expected that the estimates of α and θ from a model that allows for the accumulation of organizational capital might be quite different than those obtained from a model that ignores organizational capital. In this case, it would be necessary to estimate the structural model to obtain estimates of these production technology parameters, allowing for the accumulation of organizational capital. However, any of the advantages associated with calibrating the model would be lost. One solution to this problem would be to assume that the sum of the production technology parameters $(\alpha+\theta)$, allowing for the accumulation of organizational capital is approximately equal to estimates of the scale elasticity from models that ignore organizational capital. Consequently, after specifying the residual profit share and the sum $(\alpha + \theta)$, the implied steady state markup may be easily calculated.

This strategy has some important affects upon the calibrated values of some variables in the non-stochastic steady state. Firstly, the sum $(\alpha + \theta)$ is calibrated from existing studies that ignore the accumulation of organizational capital. Consequently, it will not depend on the values for organizational capital parameters. It has already been stated that the residual profit shares will be specified independently of the production technology and accumulation technology parameters. Therefore, the calibrated value of the steady state markup will not depend (directly) upon the organizational capital parameters. However, the calibrated value of the markup will depend upon both the sum $(\alpha + \theta)$ and the residual profit share.

Using the expressions for the markup presented in Appendix A.2, the implied value of μ, for the log-linear accumulation technology, will be given by:

$$\mu = markup \left\{ \frac{1 - \beta \exp(\chi \psi_x)(1 - \gamma)}{1 - \beta \exp(\chi \psi_x)\left[1 - \gamma(1 - \varepsilon)\right]} \right\}$$

and for the linear accumulation technology:

$$\mu = markup \left\{ \frac{1 - \beta \phi_1}{1 - \beta \phi_1 + \beta \varepsilon \phi_1 - \beta \varepsilon \exp(\chi \psi_x)} \right\}$$

Therefore, once the steady state markup has been calculated, the implied value of μ may be calculated after specifying values for β, $(\chi \psi_x)$, ε, and the organizational capital accumulation technology parameters (η, γ). The critical feature of this calibration strategy is that the demand parameter cannot be a free parameter but will instead be determined residually. It remains to consider an appropriate value for the discount rate β and the organizational capital parameters.

The expression for the steady state ratio k/y, provided in Appendix A.2, implies the following:

$$\frac{k}{y} = \frac{\theta}{markup} \frac{\beta}{1 - \beta \exp(-\chi \psi_x)(1 - \delta)}$$

It is reasonable to assume that the discount rate β and the depreciation rate of physical capital will be independent of the organizational capital parameters. Since the calibrated value of the steady state markup does not depend upon the organizational capital parameters, the steady state k/y ratio will only depend upon these organizational capital parameters to the extent that the accumulation of organizational capital alters the value of θ. Of course, the problem is that there is an infinite combination of values of θ and α that would be consistent with a constant sum of $(\alpha + \theta)$.

One strategy would involve calibrating the value of θ so that the steady state k/y ratio for the structural model *always* matches the mean k/y ratio in the data, regardless of the values of the other structural parameters. A constant k/y ratio will also produce a constant steady state i/y ratio. For an exogenous ratio of g/y, this will produce a constant c/y ratio.[15]

The measurement of the share of physical capital in output requires an appropriate definition of the aggregate capital stock and in particular a consideration of the treatment of consumer durables and government capital. The structural model outlined above assigns a passive role to the government. The public sector is a pure resource drain upon the economy and does not accumulate physical capital. Similarly, households only accumulate one form of physical capital and there is no distinction between the accumulation of physical capital and consumer durables. In general the physical capital stock will include physical capital accumulated by both households and the government. Provided the stock of private and public capital are perfect substitutes in the aggregate production technology, the capital stock may be constructed as the sum of private and public capital. This is the approach taken by Christiano & Eichenbaum (1992) and Burnside et al. (2004) where the stock of physical capital is constructed to match their definition of gross investment. Gross investment in the single capital good is measured as private sector fixed investment plus government fixed investment plus expenditures on durable goods. Consequently, the stock of physical capital is measured as the sum of the stock of consumer durables, producer structures and equipment, government and private residential capital and government non-residential capital. This definition of the stock of physical capital is much more extensive than Poterba (1998) and Atkeson & Kehoe (2002) which

[15] Although this calibration strategy appears quite restrictive, alternative values for the structural parameters might have still important consequences regarding the transitional dynamics of the model. This is explored in the next chapter.

includes only producer structures and equipment and Edelberg et al. (1999) which distinguishes between household capital and business capital.[16]

The measure of the stock of physical capital in Christiano & Eichenbaum (1992) provides a mean share of investment in output of 26.9% and a mean ratio of $k/y = 10.62$. The depreciation rate of physical capital is chosen so that the ratio of the steady state stock of physical capital to steady state output and the steady state share of investment in output match the aggregate quarterly U.S data. When there is no growth in technology, this implies a quarterly depreciation rate of $\delta = 0.0253$. When the steady state rate of growth in output is given by $(\chi\psi_x) = 0.0040$ which matches the mean (quarterly) growth rate of output in the data, the quarterly depreciation rate required to give a steady state $k/y = 10.62$ and $i/y = 0.269$ will be provided by $\delta = 0.0214$.

The rental price of physical capital in the non-stochastic steady state will be given by:

$$r_k = \frac{\exp(\chi\psi_x)}{\beta} - (1-\delta) \qquad \text{with} \qquad r = \frac{\exp(\chi\psi_x)}{\beta} - 1$$

where the real interest rate is defined as $r = r_k - \delta$, the rental price of physical capital net of depreciation. The discount rate may be set so that the real interest rate in the non-stochastic steady state coincides with the mean return to physical capital in the data. In the standard real business cycle model it is standard to use a quarterly discount rate of $\beta = 0.984$. This is chosen in order that the real interest rate is consistent with a mean annual return to physical capital of 6.5%. Following from the work of Christiano & Eichenbaum (1992), it has become standard to use a quarterly discount rate of $1.03^{-0.25}$, for models where the physical capital stock includes both private and government capital. This quarterly discount rate implies an annual real interest rate of 4.5% which is lower than that for the standard model that ignores

[16]This distinction requires an explicit structural model of the accumulation of household capital as provided in Edelberg et al. (1999).

government capital.[17]

As stated above, after setting the discount rate β and the term $(\chi\psi_x)$, the depreciation rate of physical capital is chosen to match the mean k/y and i/y ratios observed in the data. The implied value of the production technology parameter θ may then be calculated directly from the expression for the steady state k/y ratio. Once this value of θ has been calculated, the implied physical share, consistent with a steady state k/y ratio of 10.62 may be calculated according to:

$$ksh = (k/y)\,\frac{\exp(\chi\psi_x) - \beta(1-\delta)}{\beta}$$

It is important to note that since $(\chi\psi_x)$, β, δ and k/y do not depend upon the values of the organizational capital parameters, the steady state physical capital share will also be independent of these parameters.

After specifying the physical capital share, the implied labour share may be calculated based upon the specified residual profit share according to:

$$lsh = [lsh + ksh\exp(-\chi\psi_x)] - ksh\exp(-\chi\psi_x)$$

Using this calculated value for the labour share, the implied value of α might be calculated using the calibrated value of the markup according to $\alpha = (lsh \cdot markup)$.

The preference parameter Φ may be calibrated using the household first order conditions. Christiano & Eichenbaum (1992) also report a value for average per-capita hours of 320.02 per quarter for the aggregate U.S data. With a calibrated total time endowment of 1369 hours per quarter, this implies per-capita hours as a proportion of the total time endowment should be 23.38%. To capture this, the preference parameter Φ is calibrated to deliver steady state hours as a proportion of the time endowment at 23.38% according to the following:

$$\Phi = \frac{N}{H}\,lsh\,\frac{y}{c}$$

[17] Both Poterba (1998) and Atkeson & Kehoe (2002) suggest that this real return to physical capital should be somewhere in the range of 5–6%, based upon the average returns to corporate capital. However, the single capital good, used in this thesis, includes government capital and it is expected that the return to a portfolio consisting of corporate and public sector capital would be lower than this figure of 5–6%.

where

$$\frac{\bar{c}}{\bar{y}} = 1 - \frac{\bar{g}}{\bar{y}} - \frac{\bar{k}}{\bar{y}}\left[1 - (1-\delta)\exp(\chi\psi_x)\right]$$

Finally, the steady state ratio of g/y, which is assumed exogenous, is calibrated to match the mean share of government consumption observed in the data. Again, following Christiano & Eichenbaum (1992) this share is set at 17.7%. This figure has become almost standard in calibrating structural models in which government consumption is a pure resource drain on the economy.

This calibration strategy, which is summarized in Appendix B.2, has the advantage that the steady state k/y ratio will not depend upon the values of the organizational capital parameters. The next chapter studies the transitional dynamics of the structural model of organizational capital associated with an unanticipated temporary change in the level of government consumption. In particular this chapter compares these transitional dynamics for alternative values of the organizational capital parameters. If alternative values for the organizational capital parameters were associated with a different value for the k/y ratio, variation in these transitional dynamics will arise because alternative values for the organizational capital parameters affect the transition path to a given steady state *and* because these alternative values also affect the steady state itself. In contrast, the calibration strategy outlined above implies that, regardless of the values of these organizational capital parameters, the structural economy will converge to the same steady state, for a given residual profit share and sum $(\alpha + \theta)$.

Although this calibration strategy is able to determine the values of the key parameters, it relies critically upon the ability to specify appropriate values for the organizational capital parameters.

2.4.1 Calibration of the Organizational Capital Parameters

There is a well established literature that explores the relationship between production experience and plant productivity. However, the use of cumulative output as a measure of the stock of organizational capital imposes a particular structure on the accumulation technology for organizational capital. In particular, it implies a linear accumulation technology of the form (20) with $\phi_1 = 1$ and $\phi_2 = 1$. As discussed above, the restriction $0 < \phi_1 < 1$ has been imposed which excludes this possibility. In general, estimates of the productivity of organizational capital cannot be determined independently of the structural parameters governing the accumulation of organizational capital.

Benkard (2000) studies learning-by-doing in the commercial aircraft industry and extends these traditional studies of production experience by allowing for the depreciation of this production experience. The stock of production experience is determined by cumulative experience, net of depreciation. In terms of the linear accumulation technology (20), he provides estimates of ϕ_1 restricting $\phi_2 = 1$.[18] Benkard (2000) estimates a learning rate of approximately 40% with a depreciation rate of approximately 20% per quarter. However, he estimates labour requirements per unit of output for a Cobb-Douglas production technology, with a fixed stock of physical capital, of the form (17), restricting $\alpha = 1$. This learning rate of 40% implies $\varepsilon = 0.70$. This estimate for ε is likely to be implausibly large for several reasons. Restricting $\alpha = 1$ eliminates the possibility of diminishing marginal productivity associated with the labour input. In addition, a fixed stock of physical capital ignores any substitution effects between physical capital and organizational capital and physical capital and labour. This is particularly important in dynamic general equilibrium models of economic fluctuations in which the internal propagation mechanism is driven by the accumulation of physical capital.

In contrast, Cooper & Johri (2002) and Johri & Letendre (2002) restrict attention to the log-linear technology given by (19). This has the advantage that the parameters of interest may be estimated without constructing a time series for organizational capital.

Cooper & Johri (2002) and Johri & Letendre (2002) restrict attention to the case where allocation decisions are made by a social planner that maximizes the welfare of the representative agent. By studying the planner's solution they are not required to specify whether organizational capital is accumulated and stored by households or organizations. In contrast, the decentralized equilibrium solution outlined above restricts attention to the case in which organizational capital is accumulated

[18]Although, the stock of organizational capital depreciates, an additional unit of current period output produces a unit of organizational capital.

and stored by the production unit. The planner's solution imposes the restriction that worker-specific and firm-specific organizational capital are equally productive in the aggregate production technology. In addition, the existing stocks of both worker-specific and firm-specific organizational capital are equally productive in the aggregate accumulation technology.

Both Cooper & Johri (2002) and Johri & Letendre (2002) provide some estimates for the parameters $(\varepsilon, \eta, \gamma)$, imposing constant returns to scale in both the production technology and the accumulation technology. Cooper & Johri (2002) provide results from estimation of both the production technology and the accumulation technology using 2-digit quarterly manufacturing data. They report estimates of $\varepsilon = 0.08$, $\gamma = 0.37$ and $\eta = 1 - \gamma = 0.63$. Johri & Letendre (2002) report estimates of $\varepsilon = 0.24$, $\gamma = 0.05$ and $\eta = 1 - \gamma = 0.95$ based upon estimation of the full structural model.[19]

In addition, Cooper & Johri (2002) also investigate a specification that does not impose constant returns to scale in the production technology. After imposing constant returns to scale in physical capital and labour, they report estimates of $\varepsilon = 0.26$, $\gamma = 0.5$ and $\eta = 1 - \gamma = 0.5$. Relative to the case that imposes constant returns to scale, allowing for increasing returns to scale does not considerably affect the estimates of the production technology parameters α and θ but increases the returns to scale of the aggregate production technology. In addition, allowing for increasing returns to scale produces a lower estimate of the accumulation technology parameter η and a larger estimate of the productivity of organizational capital ε.

Using this limited empirical evidence, the structural model is calibrated using a range of values for the organizational capital parameters. A total of seven alternative values for ε are considered—$[0.05, 0.10, 0.12, 0.135, 0.15, 0.17, 0.195]$ and three alternative values for γ— $[0.05, 0.2, 0.35]$. For the purposes of comparison, the parameters of the linear accumulation technology are chosen to match those of the log-linear accumulation technology so that the alternative values for ϕ_1 are given by $[0.95, 0.8, 0.65]$. These values for ϕ_1 would also be consistent with the estimates of ϕ_1 provided by Benkard (2000) who restricts $\phi_2 = 1$.

[19]Note that the standard error associated with this estimate of ε is considerably lower than that in Cooper & Johri (2002). Indeed, the estimate of $\varepsilon = 0.08$ in Cooper & Johri (2002) is not significantly different from zero.

2.5 Discussion

Tables 2.1 to 2.6 provide calibrated values for the structural parameters, for the log-linear accumulation technology, for various assumptions regarding the residual profit share and the sum $(\alpha+\theta)$. Similarly, Tables 2.7 to 2.12 provide calibrated values for the structural parameters, for the linear accumulation technology, for various assumptions regarding the residual profit share and the sum $(\alpha+\theta)$. Consistent with the results provided in Basu (1996) and Basu & Fernald (1997), which suggest that the scale elasticity measured by $(\alpha + \theta)$ is close to unity, the calibrated values in Tables 2.1 to 2.6 and Tables 2.7 to 2.12 are presented for the cases $(\alpha + \theta) = 1$ and $(\alpha + \theta) = 1.1$.

Note that the organizational capital parameters for the linear accumulation technology are assumed to be identical to those for the log-linear accumulation technology. In this case there is very little difference between the calibrated values for the structural parameters for the log-linear and the linear accumulation technologies. Consequently the non-stochastic steady state implied by the log-linear accumulation technology will be approximately equivalent to the non-stochastic steady state implied by the linear technology. Indeed when there is no growth in the level of technology so that $\psi_x = 0$, these non-stochastic steady states will be identical.

This result arises because the existence of a feasible steady state imposes a particular relationship between the growth rate in organizational capital and the growth rate in output. When the accumulation technology exhibits constant returns to scale, the growth rate in organizational capital must be identical to the growth rate in output, in a feasible steady state. Note that the linear accumulation technology will exhibit (global) constant returns to scale and the log-linear technology is assumed to exhibit constant returns to scale. Consequently, the requirement that the growth rate in output be equal to the growth in organizational capital imposes an additional constraint on the feasible steady states.

This constant returns to scale assumption simply requires that the growth rate in output equals the growth rate in organizational capital. It does not require that the growth rate in output (or organizational capital) in the model with a log-linear technology equal the growth rate in output (or organizational capital) in the model with a linear technology. However, as shown above, when the accumulation technology exhibits constant returns to scale, the growth rate in output will not depend upon the organizational capital parameters and in particular it will not depend upon the functional form of the accumulation technology. Therefore, the (steady state) growth rate in organizational capital, in the model with a log-linear technology, must be identical to the steady state growth rate in organizational capital for the model with a linear technology. This considerably restricts the feasible steady states that might emerge in the model characterized by a log-linear technology, compared to the model characterized by a linear technology.

An examination of the first order conditions from the plant's maximization problem (in the transformed economy) reveals that the functional form for the accumulation technology alters the form of these first order conditions. Note that this difference in the first order conditions essentially arises because the rate of "depreciation" in organizational capital implied by the log-linear technology is quite different than that implied by the linear technology. The log-linear technology implies that a constant percentage of the stock of organizational capital is lost each period whereas the linear technology implies that a constant amount of the stock of organizational capital is lost so that the percentage of the stock that is lost will depend upon the size of the stock of organizational capital. Consequently, any difference in the non-stochastic steady states associated with these alternative accumulation technologies reflects this difference in the first order conditions while at the same time delivering the same steady state growth rate in output.

Despite the seemingly complicated calibration strategy outlined above, the calibrated values for the structural parameters presented in Tables 2.1 to 2.6 and Tables 2.7 to 2.12 appear quite reasonable. For example, a residual profit share of 1% will be associated with a labour revenue share of 64% whilst a residual profit share of 10% will be associated with a labour revenue share of 55%. Generally the mean labour revenue share in the data will depend upon the definition of labour income. However, these values for the labour revenue share are contained with an interval of generally accepted values for this mean labour revenue share.

It is worthwhile to check whether the sufficient condition for steady state profit maximization is satisfied for the calibrated values provided in Tables 2.1 to 2.6 and Tables 2.7 to 2.12. For a sufficiently small assumed residual profit share, a sufficiently small value for γ and sufficiently large values of ε, this condition will not be satisfied.

The major distinguishing feature of the calibration strategy outlined above is the treatment of the demand parameter μ. As detailed in Appendix A.2, this parameter is calculated according to:

$$\mu = markup\left\{\frac{1-\beta\exp(\chi\psi_x)(1-\gamma)}{1-\beta\exp(\chi\psi_x)\left[1-\gamma(1-\varepsilon)\right]}\right\}$$

or

$$\mu = markup\left\{\frac{1-\beta\phi_1}{1-\beta\phi_1+\beta\varepsilon\phi_1-\beta\varepsilon\exp(\chi\psi_x)}\right\}$$

For a given markup (which depends upon the sum $(\alpha+\theta)$ and the residual profit share), this required value of μ will be increasing in the value of ε, for a given value of $\gamma = 1-\phi_1$. Since the restriction $\beta\exp(\chi\psi_x) < 1$ is satisfied, this value of μ will also be increasing in the value of $\gamma = 1-\phi_1$, for a given value of ε.

A calibrated value of μ which depends upon the values of the organizational capital parameters might be interpreted in two ways, Firstly, the price elasticity of the demand curve of each intermediate goods producer will be given by:

$$\frac{\partial q_t(P_t, v_t, Y_t)}{\partial v_t}\frac{v_t}{q_t} = \frac{\mu}{1-\mu}$$

such that larger values of μ will be associated with a more elastic demand curve. This suggests that, in some sense, the accumulation of organizational capital will be associated with raising the effective price elasticity of demand for the intermediate goods producers.

There is also an alternative interpretation. By definition the residual profit share is given by $1 - lsh - ksh\exp(-\chi\psi_x)$. For a given value of α, θ, and μ, these factor revenue shares will be increasing in both ε and γ such that larger values for the organizational capital parameters will reduce the residual profit share. However, for given values of these organizational capital parameters, these factor revenue shares will also be decreasing in the value of μ. This implies that, in order to maintain a constant residual profit share, larger values of the organizational capital parameters must be offset by a larger value of μ. As discussed above, the residual profit share will be composed of both monopoly rents and payments to the owners of organizational capital. Generally, both of these components will depend upon the values of the organizational capital and the demand parameter μ. Although, the residual profit share is assumed constant, variations in both the organizational capital parameters and the demand parameter μ will alter that portion of the residual profit share due to monopoly rents and that portion reflecting payments to the owners of organizational capital.

Note that the calibration strategy presented above implies that the steady state c/y, k/y and i/y ratio will not depend upon the values of the organizational capital parameters. As such, the impact upon these steady state values of alternative values for the organizational capital parameters cannot be conducted using the calibrated values of the structural parameters provided in Tables 2.1 to 2.12. However, the comparative statics exercises detailed above, provide an indication, at least qualitatively, of how alternative values for the organizational capital parameters might affect the non-stochastic steady state, for a given value of μ, α, and θ.

Despite this, the calibrated values for the structural parameters may be used to conduct a quasi Monte Carlo experiment to examine the impact of ignoring the accumulation of organizational capital. This exercise uses the calibrated values of the structural parameters presented in Tables 2.1 to 2.6 and Tables 2.7 to 2.12 to calculate the values of some key variables in the steady state of a model that ignores the accumulation of organizational capital. Specifically, this experiment uses the values of α, θ, and μ provided in Tables 2.1 to 2.6 and Tables 2.7 to 2.12 to calibrate a model that ignores the accumulation of organizational capital. The results summarized in Table 2.13 are presented for an assumed residual profit share of 5% with the sum $(\alpha + \theta) = 1$.[20] For the sake of brevity, results are presented for a low γ case and a relatively high γ case.

As shown above, the revenue shares for the model that ignores organizational capital might be expressed as the following:

$$lsh_0 = lsh \left\{ \frac{1 - \beta \exp(\chi\psi_x) + \beta \exp(\chi\psi_x)\gamma - \beta \exp(\chi\psi_x)\gamma\varepsilon}{1 - \beta \exp(\chi\psi_x) + \beta \exp(\chi\psi_x)\gamma} \right\}$$

[20]Of course the results will depend upon the assumed residual profit share and the assumed sum $(\alpha + \theta)$.

and

$$\frac{ksh_0}{\exp(\chi_0\psi_x)} = \frac{ksh}{\exp(\chi\psi_x)} \left\{ \frac{1 - \beta\exp(\chi\psi_x) + \beta\exp(\chi\psi_x)\gamma - \beta\exp(\chi\psi_x)\gamma\varepsilon}{1 - \beta\exp(\chi\psi_x) + \beta\exp(\chi\psi_x)\gamma} \right\}$$

with

$$\left[\frac{k}{y}\right]_0 = \frac{k}{y}\frac{1 - \beta\exp(-\chi\psi_x)(1-\delta)}{1 - \beta\exp(-\chi_0\psi_x)(1-\delta)} \left\{ \frac{1 - \beta\exp(\chi\psi_x)\left[1 - \gamma(1-\varepsilon)\right]}{1 - \beta\exp(\chi\psi_x) + \beta\exp(\chi\psi_x)\gamma} \right\}$$

The calibrated values of the structural parameters imply that the bracketed terms (common to all of these expressions) will be less than unity. Therefore, the labour revenue share for the model that ignores organizational capital will always be lower than that associated with the organizational capital model.

For a given value of ψ_x, it will be true that $\exp(\chi_0\psi_x) < \exp(\chi\psi_x)$. Consequently, the physical capital share for the model that ignores organizational capital will always be lower than that associated with the organizational capital model not only because the bracketed term is less than unity but also because $\exp(\chi_0\psi_x) < \exp(\chi\psi_x)$. Similarly, the k/y ratio for the model that ignores organizational capital will always be lower than the k/y ratio in the organizational capital model. Note that the organizational capital is calibrated so that $\chi\psi_x = 0.0040$ which implies a value for ψ_x, conditional upon the value of χ. This implied value of ψ_x might be used to calculate $\exp(\chi_0\psi_x)$. However, in this case, the difference between the terms $\exp(\chi_0\psi_x)$ and $\exp(\chi\psi_x)$ will likely be extremely small.[21] Consequently, the results presented in Table 2.13 involve calibrating the model, which ignores organizational capital, with the same value of $\chi\psi_x$ rather than just the same value of ψ_x.

The qualitative results identified above are confirmed in Table 2.13. Relative to the organizational capital model, the model that ignores organizational capital implies a lower labour share, a lower physical capital share, a larger markup, a lower k/y ratio and a larger c/y ratio, for a given value of ε and γ. These lower factor revenue shares are reflected in a residual profit share that exceeds the calibrated value of 5%. It is clear from Table 2.13 that the difference between these steady state values for the model that ignores organizational capital and the organizational capital

[21] Of course, the term χ is increasing in the value of ε so that this difference will become greater for larger values of ε.

model becomes greater for larger values of ε and γ.

The model that ignores the accumulation of organizational capital contains two sources of misspecification. Since the returns to scale in this simple model will be given by the sum $(\alpha + \theta)$, the measure of the scale elasticity from this simple model will understate the true scale elasticity by the term $1/(1-\varepsilon)$. This misspecification will become relatively more serious, the larger is the value of ε. The second source of misspecification relates to the failure to account for the dynamic structure in the plant's maximization problem associated with the accumulation of organizational capital. Intuitively, larger values of ε and γ will affect the importance of the dynamic structure associated with the accumulation of organizational capital, which will affect the values of key variables in the steady state. Importantly, an examination of the expression for steady state output reveals that alternative values of ε and γ will affect the level of steady state output (and the output price). Note that it is not possible to separately identify these two sources of misspecification. This reflects that fact that it will generally not be possible to study the productivity of organizational capital without also studying the accumulation of organizational capital.

Note that:

$$\frac{\partial lsh_0}{\partial \varepsilon} = lsh \frac{-\beta \exp(\chi\psi_x)\gamma[1 - \beta \exp(\chi\psi_x)(1-\gamma)]}{[1 - \beta \exp(\chi\psi_x) + \beta \exp(\chi\psi_x)\gamma]^2} > 0$$

and

$$\frac{\partial lsh_0}{\partial \varepsilon} = lsh \frac{-\beta \exp(\chi\psi_x)\varepsilon\,[1 - \beta \exp(\chi\psi_x)]}{[1 - \beta \exp(\chi\psi_x) + \beta \exp(\chi\psi_x)\gamma]^2}$$

which will be less than zero provided $1 - \beta \exp(\chi\psi_x) > 0$. For the calibrated values of β and $(\chi\psi_x)$ this condition will be satisfied. Therefore, the bracketed term in the labour share, which is common to the k/y ratio as well, will be decreasing in ε and γ.

These results are confirmed in Table 2.13 which reveals that, relative to the organizational capital model, for a given value of γ, a larger value of ε will be associated with a lower labour revenue share, a lower physical capital share, a larger markup and a larger k/y ratio. Therefore, a larger value of ε will imply a greater divergence between the values of these steady state ratios in a model that ignores organizational capital, relative to the organizational capital model. These results will also hold for larger values of γ, for a given value of ε. This suggests that the misspecification in the simple model does not simply reflect organizational capital as an omitted productive input. There is also an important interaction between the productivity of organizational capital and the parameters of the accumulation technology.

The magnitude of the above derivatives will depend upon particular values of ε and γ. Ultimately, it is of interest to assess whether the divergence between the values of some key steady state ratios in a model that ignores organizational capital, relative to the organizational capital model, is determined primarily by the value of ε or the value of γ. Using the results from Table 2.13, Figures 2.1 and 2.2 shed some light on this issue.

Figure 2.1 plots the percentage difference between the k/y ratio for the model that ignores organizational and the value of $k/y = 10.62$ for the organizational capital model, for alternative values of γ and ε. This percentage difference is positive because the k/y in the model that ignores organizational capital is always lower than the value of 10.62. Figure 2.1 reveals that larger values of ε, for a given value of γ, appear relatively more important in producing the divergence between the k/y ratio. Alternatively, for a given value of ε, there is only a small variation in this percentage difference associated with alternative values of γ. However, Figure 2.1 confirms that it is the interaction of ε with γ that determines this percentage difference. For example, compare the results for $\gamma = 0.05$ with those associated with $\gamma = 0.35$. For relatively low values of ε, there is relatively little variation in this percentage difference for alternative values of γ. However, for larger values of ε, there is relatively larger variation in the percentage difference for alternative values of γ. Consequently, this percentage difference is greatest for larger values of both ε and γ. These results also hold for the percentage difference in steady state hours, as a proportion of the time endowment, as shown in Figure 2.2.

2.6 Conclusions

This chapter has detailed a structural model that might be used to study the accumulation of organizational capital in the aggregate economy. This structural model represents a particular decentralization of the planning solution presented in Cooper & Johri (2002). Using this structural model, this chapter has established that when production experience is accumulated and stored by production units, the implied values of several key macroeconomic variables in the non-stochastic steady state might be quite different than those implied by an otherwise identical model that ignores the accumulation of organizational capital. It was also shown that the accumulation of production experience by households, as a by-product of market work, might imply a different steady state compared to the accumulation of production experience as a joint product with the production of goods and services.

The macroeconomic effects of allowing for the production experience can only be fully understood by also studying the dynamic response of the aggregate economy to exogenous disturbances that temporarily perturb the aggregate economy away from its steady state. This is the focus of the next chapter. Since these dynamic responses will depend upon the values of key macroeconomic variables in the non-stochastic steady state, this chapter has identified that these dynamic responses might differ to those for a model that ignores organizational capital because of differences in the non-stochastic state.

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036
lsh	0.6422	0.6422	0.6422	0.6422	0.6422	0.6422	0.6422
ksh^*[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\boldsymbol{\alpha + \theta = 1}$			
θ	0.3513	0.3513	0.3513	0.3513	0.3513	0.3513	0.3513
α	0.6487	0.6487	0.6487	0.6487	0.6487	0.6487	0.6487
rts	1.0526	1.1111	1.1364	1.1561	1.1765	1.2048	1.2422
θ/α	0.5415	0.5415	0.5415	0.5415	0.5415	0.5415	0.5415
χ	1.0835	1.1822	1.2270	1.2628	1.3008	1.3551	1.4298
ψ_x	0.0037	0.0034	0.0033	0.0032	0.0031	0.0029	0.0028
$markup$	1.0101	1.0101	1.0101	1.0101	1.0101	1.0101	1.0101
				$\boldsymbol{\gamma = 0.05}$ $\boldsymbol{\eta = 0.95}$			
μ	1.0597	1.1145	1.1380	1.1563	1.1752	1.2013	1.2357
				$\boldsymbol{\gamma = 0.20}$ $\boldsymbol{\eta = 0.80}$			
μ	1.0623	1.1203	1.1452	1.1647	1.1849	1.2128	1.2497
				$\boldsymbol{\gamma = 0.35}$ $\boldsymbol{\eta = 0.65}$			
μ	1.0627	1.1211	1.1463	1.1660	1.1863	1.2146	1.2519

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α is a Cobb-Douglas production technology parameter associated with labour, θ, is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, γ and η are the parameters of the log-linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1-\theta-\varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.

[b] $ksh^* = ksh \exp(-\chi\psi_x)$

Table 2.1: Log-Linear: Residual Profit Share of 1% and $(\alpha + \theta) = 1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036
lsh	0.6422	0.6422	0.6422	0.6422	0.6422	0.6422	0.6422
ksh^{*}[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\boldsymbol{\alpha + \theta = 1.1}$			
θ	0.3864	0.3864	0.3864	0.3864	0.3864	0.3864	0.3864
α	0.7136	0.7136	0.7136	0.7136	0.7136	0.7136	0.7136
rts	1.1579	1.2222	1.2500	1.2717	1.2941	1.3253	1.3665
θ/α	0.5415	0.5415	0.5415	0.5415	0.5415	0.5415	0.5415
χ	1.2661	1.3894	1.4457	1.4910	1.5393	1.6087	1.7047
ψ_x	0.0032	0.0029	0.0028	0.0027	0.0026	0.0025	0.0023
$markup$	1.1111	1.1111	1.1111	1.1111	1.1111	1.1111	1.1111
				$\boldsymbol{\gamma = 0.05}$ $\boldsymbol{\eta = 0.95}$			
μ	1.1657	1.2259	1.2518	1.2719	1.2927	1.3215	1.3593
				$\boldsymbol{\gamma = 0.20}$ $\boldsymbol{\eta = 0.80}$			
μ	1.1686	1.2323	1.2598	1.2812	1.3034	1.3341	1.3747
				$\boldsymbol{\gamma = 0.35}$ $\boldsymbol{\eta = 0.65}$			
μ	1.1690	1.2333	1.2610	1.2826	1.3050	1.3361	1.3771

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α is a Cobb-Douglas production technology parameter associated with labour, θ is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, γ and η are the parameters of the log-linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1-\theta-\varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.

[b] $ksh^{*} = ksh \exp(-\chi\psi_x)$

Table 2.2: Log-Linear: Residual Profit Share of 1% and $(\alpha + \theta) = 1.1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034
lsh	0.6022	0.6022	0.6022	0.6022	0.6022	0.6022	0.6022
ksh^*[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\boldsymbol{\alpha+\theta=1}$			
θ	0.3661	0.3661	0.3661	0.3661	0.3661	0.3661	0.3661
α	0.6339	0.6339	0.6339	0.6339	0.6339	0.6339	0.6339
rts	1.0526	1.1111	1.1364	1.1561	1.1765	1.2048	1.2422
θ/α	0.5775	0.5775	0.5775	0.5775	0.5775	0.5775	0.5775
χ	1.0856	1.1873	1.2335	1.2706	1.3100	1.3665	1.4443
ψ_x	0.0037	0.0034	0.0032	0.0031	0.0030	0.0029	0.0028
$markup$	1.0526	1.0526	1.0526	1.0526	1.0526	1.0526	1.0526
				$\boldsymbol{\gamma=0.05}$ $\boldsymbol{\eta=0.95}$			
μ	1.1043	1.1614	1.1859	1.2050	1.2246	1.2519	1.2878
				$\boldsymbol{\gamma=0.20}$ $\boldsymbol{\eta=0.80}$			
μ	1.1071	1.1674	1.1935	1.2138	1.2348	1.2639	1.3024
				$\boldsymbol{\gamma=0.35}$ $\boldsymbol{\eta=0.65}$			
μ	1.1075	1.1683	1.1946	1.2151	1.2363	1.2657	1.3046

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α, is a Cobb-Douglas production technology parameter associated with labour, θ is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, γ and η are the parameters of the log-linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1-\theta-\varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.

[b] $ksh^* = ksh \exp(-\chi\psi_x)$

Table 2.3: Log-Linear: Residual Profit Share of 5% and $(\alpha+\theta)=1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034
lsh	0.6022	0.6022	0.6022	0.6022	0.6022	0.6022	0.6022
ksh^*[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\boldsymbol{\alpha+\theta=1.1}$			
θ	0.4027	0.4027	0.4027	0.4027	0.4027	0.4027	0.4027
α	0.6973	0.6973	0.6973	0.6973	0.6973	0.6973	0.6973
rts	1.1579	1.2222	1.2500	1.2717	1.2941	1.3253	1.3665
θ/α	0.5775	0.5775	0.5775	0.5775	0.5775	0.5775	0.5775
χ	1.2741	1.4022	1.4609	1.5083	1.5589	1.6319	1.7333
ψ_x	0.0031	0.0028	0.0027	0.0026	0.0026	0.0024	0.0023
$markup$	1.1579	1.1579	1.1579	1.1579	1.1579	1.1579	1.1579
				$\boldsymbol{\gamma=0.05}$ $\boldsymbol{\eta=0.95}$			
μ	1.2148	1.2775	1.3045	1.3255	1.3471	1.3771	1.4166
				$\boldsymbol{\gamma=0.20}$ $\boldsymbol{\eta=0.80}$			
μ	1.2178	1.2842	1.3128	1.3351	1.3582	1.3903	1.4326
				$\boldsymbol{\gamma=0.35}$ $\boldsymbol{\eta=0.65}$			
μ	1.2182	1.2852	1.3141	1.3366	1.3599	1.3923	1.4350

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α, is a Cobb-Douglas production technology parameter associated with labour, θ is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, γ and η are the parameters of the log-linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1-\theta-\varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.

[b] $ksh^* = ksh\exp(-\chi\psi_x)$

Table 2.4: Log-Linear: Residual Profit Share of 5% and $(\alpha+\theta)=1.1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
lsh	0.5522	0.5522	0.5522	0.5522	0.5522	0.5522	0.5522
ksh^{*}[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\boldsymbol{\alpha+\theta=1}$			
θ	0.3864	0.3864	0.3864	0.3864	0.3864	0.3864	0.3864
α	0.6136	0.6136	0.6136	0.6136	0.6136	0.6136	0.6136
rts	1.0526	1.1111	1.1364	1.1561	1.1765	1.2048	1.2422
θ/α	0.6298	0.6298	0.6298	0.6298	0.6298	0.6298	0.6298
χ	1.0887	1.1947	1.2431	1.2831	1.3236	1.3832	1.4658
ψ_x	0.0037	0.0033	0.0032	0.0031	0.0030	0.0029	0.0027
$markup$	1.1111	1.1111	1.1111	1.1111	1.1111	1.1111	1.1111
				$\boldsymbol{\gamma=0.05}$			
				$\boldsymbol{\eta=0.95}$			
μ	1.1657	1.2259	1.2518	1.2719	1.2927	1.3215	1.3593
				$\boldsymbol{\gamma=0.20}$			
				$\boldsymbol{\eta=0.80}$			
μ	1.1686	1.2323	1.2598	1.2812	1.3034	1.3341	1.3747
γ	0.3500	0.3500	0.3500	0.3500	0.3500	0.3500	0.3500
η	0.6500	0.6500	0.6500	0.6500	0.6500	0.6500	0.6500
μ	1.1690	1.2333	1.2610	1.2826	1.3050	1.3361	1.3771

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α is a Cobb-Douglas production technology parameter associated with labour, θ is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, γ and η are the parameters of the log-linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1-\theta-\varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.

[b] $ksh^{*} = ksh \exp(-\chi\psi_x)$

Table 2.5: Log-Linear: Residual Profit Share of 10% and $(\alpha+\theta)=1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
lsh	0.5522	0.5522	0.5522	0.5522	0.5522	0.5522	0.5522
ksh^{*}[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\boldsymbol{\alpha + \theta = 1.1}$			
θ	0.4251	0.4251	0.4251	0.4251	0.4251	0.4251	0.4251
α	0.6749	0.6749	0.6749	0.6749	0.6749	0.6749	0.6749
rts	1.1579	1.2222	1.2500	1.2717	1.2941	1.3253	1.3665
θ/α	0.6298	0.6298	0.6298	0.6298	0.6298	0.6298	0.6298
χ	1.2858	1.4211	1.4836	1.5342	1.5884	1.6668	1.7765
ψ_x	0.0031	0.0028	0.0027	0.0026	0.0025	0.0024	0.0022
$markup$	1.2222	1.2222	1.2222	1.2222	1.2222	1.2222	1.2222
				$\boldsymbol{\gamma = 0.05}$ $\boldsymbol{\eta = 0.95}$			
μ	1.2823	1.3490	1.3769	1.3991	1.4220	1.4536	1.4953
				$\boldsymbol{\gamma = 0.20}$ $\boldsymbol{\eta = 0.80}$			
μ	1.2854	1.3555	1.3857	1.4093	1.4337	1.4675	1.5122
				$\boldsymbol{\gamma = 0.35}$ $\boldsymbol{\eta = 0.65}$			
μ	1.2859	1.3566	1.3871	1.4109	1.4355	1.4697	1.5148

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α is a Cobb-Douglas production technology parameter associated with labour, θ is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, γ and η are the parameters of the log-linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1-\theta-\varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.

[b] $ksh^{*} = ksh \exp(-\chi\psi_x)$

Table 2.6: Log-Linear: Residual Profit Share of 10% and $(\alpha + \theta) = 1.1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036
lsh	0.6422	0.6422	0.6422	0.6422	0.6422	0.6422	0.6422
ksh^*[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\boldsymbol{\alpha+\theta=1}$			
θ	0.3513	0.3513	0.3513	0.3513	0.3513	0.3513	0.3513
α	0.6487	0.6487	0.6487	0.6487	0.6487	0.6487	0.6487
rts	1.0526	1.1111	1.1364	1.1561	1.1765	1.2048	1.2422
θ/α	0.5415	0.5415	0.5415	0.5415	0.5415	0.5415	0.5415
χ	1.0835	1.1822	1.2270	1.2628	1.3008	1.3551	1.4298
ψ_x	0.0037	0.0034	0.0033	0.0032	0.0031	0.0030	0.0028
$markup$	1.0101	1.0101	1.0101	1.0101	1.0101	1.0101	1.0101
				$\boldsymbol{\phi_2=0.05}$ $\boldsymbol{\phi_1=0.95}$			
μ	1.0600	1.1150	1.1386	1.1570	1.1760	1.2024	1.2370
				$\boldsymbol{\phi_2=0.20}$ $\boldsymbol{\phi_1=0.80}$			
μ	1.0623	1.1203	1.1453	1.1648	1.1849	1.2129	1.2498
				$\boldsymbol{\phi_2=0.35}$ $\boldsymbol{\phi_1=0.65}$			
μ	1.0627	1.1211	1.1464	1.1660	1.1864	1.2146	1.2519

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α is a Cobb-Douglas production technology parameter associated with labour, θ is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, ϕ_1 and ϕ_2 are the parameters of the linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1-\theta-\varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.
[b] $ksh^* = ksh\exp(-\chi\psi_x)$

Table 2.7: Linear: Residual Profit Share of 1% and $(\alpha+\theta)=1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036
lsh	0.6422	0.6422	0.6422	0.6422	0.6422	0.6422	0.6422
ksh^*[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\alpha + \theta = 1.1$			
θ	0.3864	0.3864	0.3864	0.3864	0.3864	0.3864	0.3864
α	0.7136	0.7136	0.7136	0.7136	0.7136	0.7136	0.7136
rts	1.1579	1.2222	1.2500	1.2717	1.2941	1.3253	1.3665
θ/α	0.5415	0.5415	0.5415	0.5415	0.5415	0.5415	0.5415
χ	1.2662	1.3894	1.4457	1.4910	1.5393	1.6087	1.7047
ψ_x	0.0032	0.0029	0.0028	0.0027	0.0026	0.0025	0.0023
$markup$	1.1111	1.1111	1.1111	1.1111	1.1111	1.1111	1.1111
				$\phi_2 = 0.05$			
				$\phi_1 = 0.95$			
μ	1.1659	1.2265	1.2525	1.2727	1.2936	1.3226	1.3607
				$\phi_2 = 0.20$			
				$\phi_1 = 0.80$			
μ	1.1686	1.2323	1.2598	1.2812	1.3034	1.3342	1.3748
				$\phi_2 = 0.35$			
				$\phi_1 = 0.65$			
μ	1.1690	1.2333	1.2610	1.2826	1.3050	1.3361	1.3771

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α is a Cobb-Douglas production technology parameter associated with labour, θ is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, ϕ_1 and ϕ_2 are the parameters of the linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1 - \theta - \varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.

[b] $ksh^* = ksh \exp(-\chi\psi_x)$

Table 2.8: Linear: Residual Profit Share of 1% and $(\alpha + \theta) = 1.1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034
lsh	0.6022	0.6022	0.6022	0.6022	0.6022	0.6022	0.6022
ksh^{*}[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\boldsymbol{\alpha+\theta=1}$			
θ	0.3661	0.3661	0.3661	0.3661	0.3661	0.3661	0.3661
α	0.6339	0.6339	0.6339	0.6339	0.6339	0.6339	0.6339
rts	1.0526	1.1111	1.1364	1.1561	1.1765	1.2048	1.2422
θ/α	0.5775	0.5775	0.5775	0.5775	0.5775	0.5775	0.5775
χ	1.0856	1.1873	1.2335	1.2706	1.3100	1.3664	1.4443
ψ_x	0.0037	0.0034	0.0032	0.0031	0.0031	0.0029	0.0028
$markup$	1.0526	1.0526	1.0526	1.0526	1.0526	1.0526	1.0526
				$\boldsymbol{\phi_2=0.05}$ $\boldsymbol{\phi_1=0.95}$			
μ	1.1046	1.1619	1.1866	1.2057	1.2255	1.2530	1.2891
				$\boldsymbol{\phi_2=0.20}$ $\boldsymbol{\phi_1=0.80}$			
μ	1.1071	1.1675	1.1935	1.2138	1.2348	1.2640	1.3024
				$\boldsymbol{\phi_2=0.35}$ $\boldsymbol{\phi_1=0.65}$			
μ	1.1075	1.1684	1.1946	1.2151	1.2363	1.2658	1.3046

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α is a Cobb-Douglas production technology parameter associated with labour, θ is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, ϕ_1 and ϕ_2 are the parameters of the linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1-\theta-\varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.
[b] $ksh^{*} = ksh\exp(-\chi\psi_x)$

Table 2.9: Linear: Residual Profit Share of 5% and $(\alpha+\theta)=1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034
lsh	0.6022	0.6022	0.6022	0.6022	0.6022	0.6022	0.6022
ksh^{*}[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\boldsymbol{\alpha+\theta=1.1}$			
θ	0.4027	0.4027	0.4027	0.4027	0.4027	0.4027	0.4027
α	0.6973	0.6973	0.6973	0.6973	0.6973	0.6973	0.6973
rts	1.1579	1.2222	1.2500	1.2717	1.2941	1.3253	1.3665
θ/α	0.5775	0.5775	0.5775	0.5775	0.5775	0.5775	0.5775
χ	1.2741	1.4022	1.4609	1.5083	1.5589	1.6318	1.7332
ψ_x	0.0031	0.0029	0.0027	0.0027	0.0026	0.0025	0.0023
$markup$	1.1579	1.1579	1.1579	1.1579	1.1579	1.1579	1.1579
				$\boldsymbol{\phi_2=0.05}$			
				$\boldsymbol{\phi_1=0.95}$			
μ	1.2150	1.2781	1.3052	1.3263	1.3481	1.3783	1.4180
				$\boldsymbol{\phi_2=0.20}$			
				$\boldsymbol{\phi_1=0.80}$			
μ	1.2178	1.2842	1.3128	1.3352	1.3583	1.3904	1.4327
				$\boldsymbol{\phi_2=0.35}$			
				$\boldsymbol{\phi_1=0.65}$			
μ	1.2182	1.2852	1.3141	1.3366	1.3599	1.3923	1.4351

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α is a Cobb-Douglas production technology parameter associated with labour, θ is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, ϕ_1 and ϕ_2 are the parameters of the linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1-\theta-\varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.

[b] $ksh^{*} = ksh \exp(-\chi\psi_x)$

Table 2.10: Linear: Residual Profit Share of 5% and $(\alpha+\theta)=1.1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
lsh	0.5522	0.5522	0.5522	0.5522	0.5522	0.5522	0.5522
ksh^*[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\boldsymbol{\alpha+\theta=1}$			
θ	0.3864	0.3864	0.3864	0.3864	0.3864	0.3864	0.3864
α	0.6136	0.6136	0.6136	0.6136	0.6136	0.6136	0.6136
rts	1.0526	1.1111	1.1364	1.1561	1.1765	1.2048	1.2422
θ/α	0.6298	0.6298	0.6298	0.6298	0.6298	0.6298	0.6298
χ	1.0887	1.1947	1.2431	1.2831	1.3236	1.3832	1.4658
ψ_x	0.0037	0.0033	0.0032	0.0031	0.0030	0.0029	0.0027
$markup$	1.1111	1.1111	1.1111	1.1111	1.1111	1.1111	1.1111
				$\boldsymbol{\phi_2=0.05}$			
				$\boldsymbol{\phi_1=0.95}$			
μ	1.1659	1.2265	1.2525	1.2727	1.2936	1.3226	1.3607
				$\boldsymbol{\phi_2=0.20}$			
				$\boldsymbol{\phi_1=0.80}$			
μ	1.1686	1.2323	1.2598	1.2812	1.3034	1.3342	1.3748
				$\boldsymbol{\phi_2=0.35}$			
				$\boldsymbol{\phi_1=0.65}$			
μ	1.1690	1.2333	1.2610	1.2826	1.3050	1.3361	1.3771

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α is a Cobb-Douglas production technology parameter associated with labour, θ is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, ϕ_1 and ϕ_2 are the parameters of the linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1-\theta-\varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.
[b] $ksh^* = ksh\exp(-\chi\psi_x)$

Table 2.11: Linear: Residual Profit Share of 10% and $(\alpha+\theta)=1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
Φ	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
lsh	0.5522	0.5522	0.5522	0.5522	0.5522	0.5522	0.5522
ksh^*[b]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
				$\alpha + \theta = 1.1$			
θ	0.4251	0.4251	0.4251	0.4251	0.4251	0.4251	0.4251
α	0.6749	0.6749	0.6749	0.6749	0.6749	0.6749	0.6749
rts	1.1579	1.2222	1.2500	1.2717	1.2941	1.3253	1.3665
θ/α	0.6298	0.6298	0.6298	0.6298	0.6298	0.6298	0.6298
χ	1.2857	1.4211	1.4836	1.5342	1.5883	1.6668	1.7764
ψ_x	0.0031	0.0028	0.0027	0.0026	0.0025	0.0024	0.0023
$markup$	1.2222	1.2222	1.2222	1.2222	1.2222	1.2222	1.2222
				$\phi_2 = 0.05$			
				$\phi_1 = 0.95$			
μ	1.2825	1.3491	1.3777	1.4000	1.4230	1.4549	1.4968
				$\phi_2 = 0.20$			
				$\phi_1 = 0.80$			
μ	1.2854	1.3555	1.3858	1.4094	1.4338	1.4676	1.5123
				$\phi_2 = 0.35$			
				$\phi_1 = 0.65$			
μ	1.2859	1.3566	1.3871	1.4109	1.4355	1.4697	1.5148

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α is a Cobb-Douglas production technology parameter associated with labour, θ is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, ϕ_1 and ϕ_2 are the parameters of the linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1-\theta-\varepsilon)$.
[b] $ksh^* = ksh\exp(-\chi\psi_x)$

Table 2.12: Linear: Residual Profit Share of 10% and $(\alpha + \theta) = 1.1$

ε	0.0500	0.1000	0.1200	0.1350	0.1500	0.1700	0.1950
	Log-Linear Accumulation Technology						
k/y	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200	10.6200
lsh	0.6022	0.6022	0.6022	0.6022	0.6022	0.6022	0.6022
ksh^{*}[a]	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478	0.3478
$lsh + ksh^*$	0.9500	0.9500	0.9500	0.9500	0.9500	0.9500	0.9500
h/T	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
i/y	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690	0.2690
c/y	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540	0.5540
	$\boldsymbol{\alpha + \theta = 1}$						
rts	1.0526	1.1111	1.1364	1.1561	1.1765	1.2048	1.2422
$markup$	1.0526	1.0526	1.0526	1.0526	1.0526	1.0526	1.0526
	Ignoring Organizational Capital						
	$\boldsymbol{\gamma = 0.05}$						
k/y	10.1228	9.6255	9.4266	9.2775	9.1283	8.9294	8.6808
lsh	0.5740	0.5458	0.5346	0.5261	0.5176	0.5064	0.4923
ksh^*	0.3315	0.3152	0.3087	0.3038	0.2989	0.2924	0.2843
$lsh + ksh^*$	0.9055	0.8610	0.8432	0.8299	0.8166	0.7988	0.7765
h/T	0.2179	0.2027	0.1968	0.1924	0.1881	0.1824	0.1755
i/y	0.2564	0.2438	0.2388	0.2350	0.2312	0.2262	0.2199
c/y	0.5666	0.5792	0.5842	0.5880	0.5918	0.5968	0.6031
rts	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
$markup$	1.1043	1.1614	1.1859	1.2050	1.2246	1.2519	1.2878
	$\boldsymbol{\gamma = 0.35}$						
k/y	10.0941	9.5682	9.3578	9.2001	9.0423	8.8319	8.5690
lsh	0.5724	0.5426	0.5307	0.5217	0.5128	0.5008	0.4859
ksh^*	0.3305	0.3133	0.3064	0.3013	0.2961	0.2892	0.2806
$lsh + ksh^*$	0.9030	0.8559	0.8371	0.8230	0.8089	0.7901	0.7665
h/T	0.2170	0.2009	0.1947	0.1902	0.1856	0.1797	0.1724
i/y	0.2557	0.2424	0.2370	0.2330	0.2290	0.2237	0.2170
c/y	0.5673	0.5806	0.5860	0.5900	0.5940	0.5993	0.6060
rts	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
$markup$	1.1075	1.1683	1.1946	1.2151	1.2363	1.2657	1.3046

[a] $ksh^* = ksh \exp(-\chi\psi_x)$

Table 2.13: No Organizational Capital: $(\alpha + \theta) = 1$

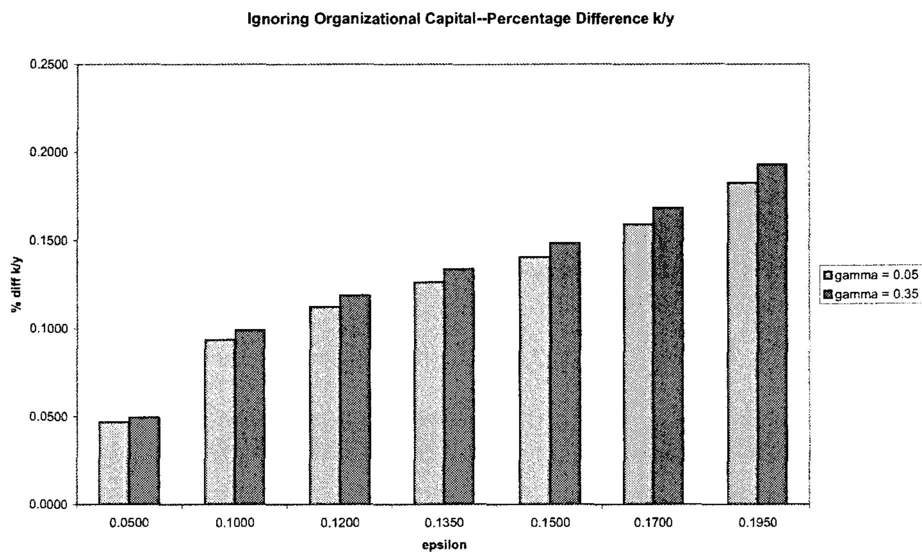

Figure 2.1: Ignoring Organizational Capital—k/y ratio

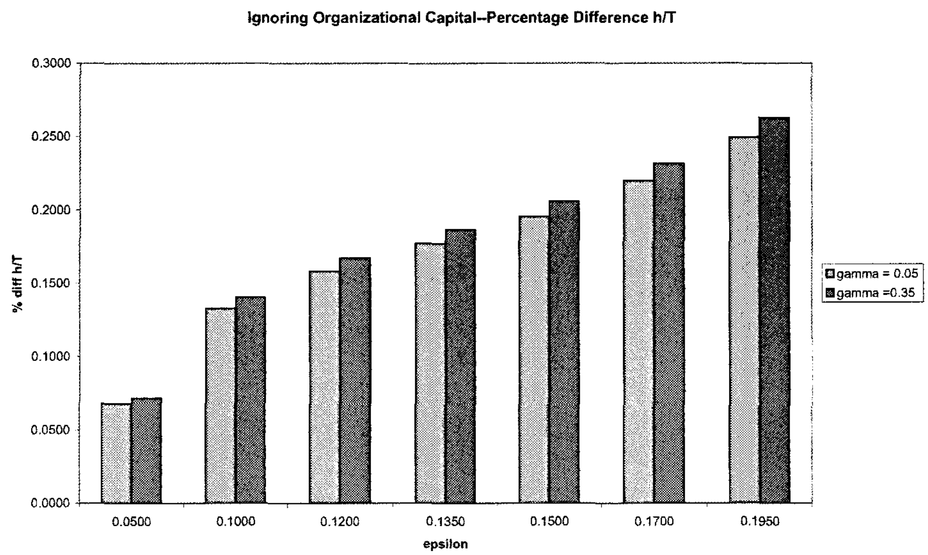

Figure 2.2: Ignoring Organizational Capital—Hours

A.2 Appendix: The Non–Stochastic Steady State

A.2.1 No Organizational Capital

$$y = k^{\theta} h^{\alpha} \exp\left[-(\theta\chi\psi_x)\right] \qquad \chi = \alpha + \theta \tag{A.2.1}$$

$$lsh = \frac{\alpha}{\mu} \tag{A.2.2}$$

$$ksh = \frac{\theta \exp(\chi\psi_x)}{\mu} \tag{A.2.3}$$

$$markup = \mu \tag{A.2.4}$$

$$\frac{\bar{k}}{\bar{y}} = \frac{\theta}{\mu} \frac{\beta}{1 - \beta \exp(-\chi\psi_x)(1-\delta)} \tag{A.2.5}$$

$$\frac{\bar{c}}{\bar{y}} = 1 - \frac{\bar{g}}{\bar{y}} - \frac{\bar{k}}{\bar{y}} \left[1 - (1-\delta) \exp(-\chi\psi_x)\right] \tag{A.2.6}$$

A.2.2 Log-Linear Accumulation Technology

$$y = \exp\left[-\chi\psi_x\left(\frac{\theta\gamma+\varepsilon}{\gamma(1-\varepsilon)}\right)\right]\ \left\{k^{\theta\gamma}\, H^{\alpha\gamma}\right\}^{\gamma(1-\varepsilon)^{-1}} \tag{A.2.7}$$

$$z = \left\{k^{\theta\gamma}\, H^{\alpha\gamma}\ \exp\left[-\chi\psi_x(1-\gamma(1-\varepsilon)+\theta\gamma)\right]\right\}^{(\gamma(1-\varepsilon)^{-1}} \tag{A.2.8}$$

$$lsh = \frac{\alpha}{\mu}\left\{\frac{1-\beta\exp(\chi\psi_x)(1-\gamma)}{1-\beta\exp(\chi\psi_x)\left[1-\gamma(1-\varepsilon)\right]}\right\} \tag{A.2.9}$$

$$ksh = \frac{\theta\exp(\chi\psi_x)}{\mu}\left\{\frac{1-\beta\exp(\chi\psi_x)(1-\gamma)}{1-\beta\exp(\chi\psi_x)\left[1-\gamma(1-\varepsilon)\right]}\right\} \tag{A.2.10}$$

$$markup = \mu\left\{\frac{1-\beta\exp(\chi\psi_x)\left[1-\gamma(1-\varepsilon)\right]}{1-\beta\exp(\chi\psi_x)(1-\gamma)}\right\} \tag{A.2.11}$$

$$\frac{\bar{k}}{\bar{y}} = \frac{\theta}{\mu}\,\frac{\beta}{1-\beta\exp(-\chi\psi_x)(1-\delta)}\left\{\frac{1-\beta\exp(\chi\psi_x)(1-\gamma)}{1-\beta\exp(\chi\psi_x)\left[1-\gamma(1-\varepsilon)\right]}\right\} \tag{A.2.12}$$

$$\frac{\bar{z}}{\bar{y}} = \exp\left[-\chi\psi_x\left\{\frac{1-\gamma}{\gamma}\right\}\right] \tag{A.2.13}$$

$$\frac{\bar{c}}{\bar{y}} = 1-\frac{\bar{g}}{\bar{y}}-\frac{\bar{k}}{\bar{y}}\left[1-(1-\delta)\ \exp(-\chi\psi_x)\right] \tag{A.2.14}$$

A.2.3 Linear Accumulation Technology

$$y = \left\{k^{\theta}\, H^{\alpha}\right\}^{(1-\varepsilon)^{-1}} \left\{\left[\frac{\phi_2}{1-\phi_1 \exp(-\chi\psi_x)}\right]^{-\varepsilon}\right\}^{(1-\varepsilon)^{-1}} \exp\left[-\chi\psi_x\left(\frac{\theta+\varepsilon}{1-\varepsilon}\right)\right] \tag{A.2.15}$$

$$z = \left\{k^{-\theta}\, H^{-\alpha}\right\}^{(\varepsilon-1)^{-1}} \left[\frac{\phi_2}{1-\phi_1 \exp(-\chi\psi_x)}\right]^{(\varepsilon-1)^{-1}} \exp\left[\chi\psi_x\left(\frac{\theta+\varepsilon}{\varepsilon-1}\right)\right] \tag{A.2.16}$$

$$lsh = \frac{\alpha}{\mu}\left\{\frac{1-\beta\phi_1}{1-\beta\phi_1+\beta\varepsilon\phi_1-\beta\varepsilon\exp(\chi\psi_x)}\right\} \tag{A.2.17}$$

$$ksh = \frac{\theta\exp(\chi\psi_x)}{\mu}\left\{\frac{1-\beta\phi_1}{1-\beta\phi_1+\beta\varepsilon\phi_1-\beta\varepsilon\exp(\chi\psi_x)}\right\} \tag{A.2.18}$$

$$markup = \mu\left\{\frac{1-\beta\phi_1+\beta\varepsilon\phi_1-\beta\varepsilon\exp(\chi\psi_x)}{1-\beta\phi_1}\right\} \tag{A.2.19}$$

$$\frac{\bar{z}}{\bar{y}} = \frac{\phi_2}{1-\phi_1\exp(-\chi\psi_x)} \tag{A.2.20}$$

$$\frac{\bar{k}}{\bar{y}} = \frac{\theta}{\mu}\,\frac{\beta}{1-\beta\exp(-\chi\psi_x)(1-\delta)}\left\{\frac{1-\beta\phi_1}{1-\beta\phi_1+\beta\varepsilon\phi_1-\beta\varepsilon\exp(\chi\psi_x)}\right\} \tag{A.2.21}$$

$$\frac{\bar{c}}{\bar{y}} = 1-\frac{\bar{g}}{\bar{y}}-\frac{\bar{k}}{\bar{y}}\left[1-(1-\delta)\,\exp(-\chi\psi_x)\right] \tag{A.2.22}$$

B.2 Appendix: Summary of Calibration Strategy

1. set value of $(\alpha + \theta)$ from literature

2. set $[lsh + ksh \exp(-\chi\psi_x)]$

3. calculate:
$$markup = \frac{\alpha + \theta}{lsh + ksh \exp(-\chi\psi_x)}$$

4. use the mean growth rate in output in the data to set $(\chi\psi_x)$

5. use mean k/y ratio and mean i/y ratio in the data

6. specify a value for β based upon the mean return to physical capital

7. calculate:
$$\delta = 1 - \left[\exp(\chi\psi_x)\left(1 - \frac{i/y}{k/y}\right)\right]$$

8. calculate
$$ksh = (k/y)\frac{\exp(\chi\psi_x) - \beta(1-\delta)}{\beta}$$

9. $lsh = [lsh + ksh \exp(-\chi\psi_x)] - ksh \exp(-\chi\psi_x)$

10. $\alpha = lsh \cdot markup$

11. $\theta = (\alpha + \theta) - \alpha$

12. calculate for values of ε and γ
$$\mu = markup \left\{\frac{1 - \beta \exp(\chi\psi_x)(1-\gamma)}{1 - \beta \exp(\chi\psi_x)\left[1 - \gamma(1-\varepsilon)\right]}\right\}$$
or for ε and ϕ_1
$$\mu = markup \left\{\frac{1 - \beta\phi_1}{1 - \beta\phi_1 + \beta\varepsilon\phi_1 - \beta\varepsilon \exp(\chi\psi_x)}\right\}$$

13. calculate
$$\chi = \frac{\alpha}{1 - \theta - \varepsilon} \qquad \text{and} \qquad \psi_x = \frac{\chi\psi_x}{\chi}$$

3 Organizational Capital, Government Consumption and Aggregate Fluctuations

3.1 Introduction

Typically, the macroeconomic effects of allowing for the accumulation of production experience have been studied in terms of a choice problem solved by a social planner. These studies do not consider distinct households or production units and are not required to specify whether production experience is accumulated by households or firms. Since production experience will likely be accumulated by both households and production units such an approach is quite convenient. Despite this, our interest in the macroeconomic implications of allowing for the accumulation of production experience is ultimately motivated by a desire to understand how stabilization policy should be conducted in the presence of these learning effects. Before any policy conclusions can be reached, it is necessary to understand whether the macroeconomic effects associated with the accumulation of experience by households are fundamentally different from the effects associated with the accumulation of experience by production units.

The previous chapter has established that when production experience is accumulated and stored by production units, the implied values of several key macroeconomic variables in the non-stochastic steady state might be quite different than those implied by an otherwise identical model that ignores the accumulation of organizational capital. It was also shown that the accumulation of production experience by households, as a by-product of market work, might imply a different steady state compared to the accumulation of production experience as a joint product with the production of goods and services. Although these results are important, the macroeconomic effects of allowing for production experience can only be fully understood by also studying the dynamic response of the aggregate economy to exogenous disturbances that temporarily perturb the aggregate economy away from its steady state.

The interest in the behaviour of the aggregate economy outside the non-stochastic steady state is primarily motivated by the weak internal propagation mechanism of the standard dynamic general equilibrium model. It is well known that aggregate output has an important trend reverting component that is characterized by a hump-shaped response to a transitory shock.[1] As noted by Cogley & Nason (1995), aggregate output in the standard real business cycle model displays a monotonic response to a transitory shock. Fundamentally, the output dynamics in the standard real business cycle model are essentially the same as the impulse dynamics. This suggests that the internal propagation mechanism associated with the accumulation of physical capital and the intertemporal substitution of consumption and leisure is extremely weak. This has prompted numerous authors to search for alternative sources of endogenous propagation, beyond those associated with physical capital accumulation.

As shown by Cooper & Johri (1997, 2002) and Chang et al. (2002), structural models that allow for the accumulation of organizational capital might be capable of generating such an endogenous propagation mechanism.[2] This previous work has concentrated upon two types of exogenous disturbances. Cooper & Johri (2002) study the dynamic response of the aggregate economy to a technology shock. Alternatively, Chang et al. (2002) consider economic fluctuations driven by demand variations, modelled as a shock that affects the marginal rate of substitution between consumption and leisure, for the representative agent.

In contrast, this chapter considers an alternative disturbance in the form of an exogenous unanticipated increase in government consumption. The study of the dynamic response of the aggregate economy to such a fiscal shock is of particular interest for several reasons. Firstly, demand shocks, which affect production rates, might have an important effect upon the stock of organizational capital available to the production unit. The interaction of this form of exogenous disturbance with

[1]Blanchard & Quah (1989) and Cogley & Nason (1995).

[2]In contrast to these other papers, Johri & Letendre (2002) focus upon the persistence in the residuals of the estimated first order conditions from the standard real business cycle model. They show that, allowing for the accumulation of production experience, which generates a dynamic labour supply first order condition, considerably reduces this persistence.

the accumulation of production experience has not been studied previously. Consequently, this chapter supplements our understanding of the endogenous propagation mechanism associated with the accumulation of organizational capital.

Secondly, economists have long been interested in the effect of an increase in government purchases upon the aggregate economy. Consequently, there is an important literature that explores the effects of government spending in dynamic general equilibrium models. The dynamic response of the standard real business cycle model to a fiscal shock is well understood. This provides a benchmark by which the endogenous propagation mechanism associated with the accumulation of production experience might be evaluated, at least qualitatively, by comparing the dynamic responses to the implied dynamic responses of the standard real business cycle model.

As discussed in the previous chapter, when organizational capital is treated as an input in the production technology, the accumulation of production experience might be associated with internal increasing returns to scale. There are several papers that explore the response of the aggregate economy to a fiscal shock in the presence of increasing returns to scale. Technically, these papers generate results that differ from the standard real business cycle because saddle path stability need not necessarily hold in the presence of increasing returns to scale. When attention is restricted to equilibria in which this saddle path stability is satisfied, the results from these models are not considerably different than those associated with the standard real business cycle model.

The structural model outlined in the previous chapter provides an explicit microeconomic foundation for the existence of these (internal) increasing returns to scale, even in the absence of free entry. In addition, the joint hypothesis of monopolistic competition and the accumulation of organizational capital implies that production units face a tradeoff between maximizing current profits and losing future productivity increases. This chapter examines whether the transitional dynamics implied by this structural model are considerably different from those implied by some existing structural models, even in the region of saddle path stability.

In addition to identifying any differences in the dynamic responses arising from the accumulation of organizational capital, compared to a model which ignores organizational capital, this chapter also explores whether these theoretical responses to a fiscal shock depend critically upon either the values of the organizational capital parameters or the functional form of the accumulation technology. Although Cooper & Johri (2002) and Johri & Letendre (2002) provide some structural estimates of the organizational capital parameters, there is considerable variation in their estimates. The previous chapter has detailed the impact of alternative assumptions regarding the values of these parameters upon the steady state values of some key macroeconomic variables. However it is also important to understand how alternative values of these organizational capital parameters affect the behaviour of key macroeconomic variables outside the steady state.

The (limited) literature that explores the impact of allowing for the accumulation of organizational capital upon macroeconomic fluctuations has restricted attention to the log-linear accumulation technology. However, the microeconomic literature studying learning-by-doing has largely restricted attention to the linear accumulation technology. A comparison of the dynamic responses for a linear technology, compared to those for the log-linear technology, allows a study of these two approaches to the modelling of learning-by-doing. Although, the log-linear accumulation technology has some advantages in relation to the (structural) estimation of the organizational capital parameters, Cooper & Johri (2002) and Johri & Letendre (2002) simply impose this functional form assumption. It is important to understand the implications of this functional form assumption. The previous chapter has shown that the particular functional form assumption for the accumulation technology has relatively little impact upon the values of key variables in the steady state. Despite this, it is important to examine whether the particular function form for the accumulation technology has any considerable effects upon the out of steady state behaviour of the aggregate economy. This chapter explores whether there are any significant differences in the (theoretical) dynamic responses to a fiscal shock for the log-linear technology compared to those for the linear technology.

In summary, this chapter studies the dynamic responses of an aggregate economy, in which there is accumulation of organizational, to a fiscal shock. This objective is achieved in several ways. Firstly, this chapter compares the dynamic responses arising from a model that allows for the accumulation of organizational capital to a model that ignores this accumulation of organizational capital. Secondly, this chapter explores whether these dynamic responses depend critically upon either the values for the organizational capital parameters or the functional form for the accumulation technology.

An evaluation of the endogenous propagation mechanism associated with the accumulation of organizational capital requires an understanding of the empirical response of the aggregate economy to a fiscal shock. The macroeconomic effects of allowing for the accumulation of production experience will be important to the extent that they produce dynamic responses that are consistent with, at least some, of the stylized facts associated with the empirical responses.

3.2 The Output Effects of Government Consumption

The response of key macroeconomic variables to an increase in government purchases is an important area that has interested macroeconomists for several generations. This interest is partly motivated by a desire to evaluate the properties of alternative rules and institutions involved in the setting of fiscal policy. As suggested by Christiano et al. (1999), in reference to monetary policy, the absence of appropriate natural experiments in which otherwise identical economies are observed to operate under different fiscal regimes implies that structural models are needed to conduct these experiments. The strategy outlined by Christiano et al. (1999) and applied to fiscal policy in Edelberg et al. (1999) involves comparing the predictions of alternative (structural) models to a particular shock. For this strategy to be useful, it is necessary that researchers understand how the actual economy responds to this shock.

The major difficulty in conducting these comparisons is the need to identify changes in government purchases that are truly exogenous. Ramey & Shapiro (1998) focus upon exogenous movements in defence spending as a proxy for exogenous movements in total government purchases. They identify political events that led to three large military buildups in the U.S. economy—The Korean War, The Vietnam War and the Carter-Reagan military buildup. Edelberg et al. (1999) document the impact upon the U.S. economy of an average increase in defence expenditures across these three Ramey-Shapiro episodes.

Eichenbaum & Fisher (1998), Edelberg et al. (1999) and Burnside et al. (2004) summarize the (empirical) dynamic responses of key macroeconomic variables to the onset of a Ramey-Shapiro episode. The onset of a Ramey-Shapiro episode leads to a large, persistent, hump-shaped rise in defence expenditures and total government purchases. There is a delayed hump-shaped increase in real output. Total private employment rises in a hump-shaped way, reflecting the hump-shaped response in defence expenditures and government purchases. Eichenbaum & Fisher (1998) and Edelberg et al. (1999) consider several alternative measures of real wages and report that, for each of these measures, real wages fall in response to the onset of a Ramey-Shapiro episode. In addition, after-tax real wages fall by more than before tax real wages. While these empirical results would be consistent with a simple variant of the real business cycle model, they pose a sharp challenge to models such as Devereux et al. (1996) in which real wages increase following a positive shock to government purchases.

The results presented in Burnside et al. (2004) reveal that (total) consumption does not respond strongly to the fiscal shock. At the same time, investment initially rises and then quickly declines. This is in sharp contrast to the predictions from the standard real business cycle model in which a highly persistent shock to government consumption leads to large persistent fall in consumption and a large persistent increase in investment.

Note that this response of investment and consumption depends critically upon the particular definition of gross investment. In Burnside et al. (2004), consumption includes expenditures on non-durable goods and services and an imputed service flow from consumer durables. Investment includes expenditures on consumer durable goods, residential capital and non-residential capital.

Edelberg et al. (1999) provide an alternative definition of total consumption which includes expenditures on both durable and non-durable consumption goods. Following a positive government shock, expenditures on non-durable goods fall after a brief delay. However, a positive government shock also induces a initial rise in expenditures on durable goods. Despite this, the combined response in non-durable and durable consumption expenditures is quite small. This is consistent with the results presented in Burnside et al. (2004).

Edelberg et al. (1999) further suggest that expenditures on consumer durables and expenditures on residential capital might be appropriately classified as investment in some form of household capital. They show that, in response to a positive government shock, expenditures on household capital initially rise but within 2 quarters falls below its pre-shock level with a peak (negative) response after approximately 8 quarters. The results in Edelberg et al. (1999) also suggest that a positive shock to government purchases induces a persistent rise in non-residential investment with the peak response approximately six quarters after the shock. This shock is also associated with a delayed fall in consumption expenditures mainly due to a reduction in investment in household capital.

The results presented in Edelberg et al. (1999) might be qualitatively consistent with a standard neoclassical model where total consumption expenditures are defined to include both expenditures on non-durables and expenditures on household capital (expenditures on durables and residential capital). Consequently, investment would be defined as investment in non-residential capital. As suggested by Edelberg et al. (1999), the consumption dynamics would be dominated by the dynamics associated with investment in household capital.

Of course, these interpretations of total consumption and investment would be consistent with the standard real business cycle which typically assumes the presence of a single capital good. As such they do not provide an explicit foundation for the evolution of household capital so that the dynamic response of (total) investment, with a single capital good, essentially describes the dynamics associated with investment in non-residential capital.

Consequently, when the implied dynamics of investment in the standard real business cycle are reinterpreted as representing the dynamics of non-residential investment, the failure of this model to match the stylized facts must be reassessed. This failure essentially reflects an inability to generate a hump-shaped response in non-residential investment. This would be consistent with the critique of Cogley & Nason (1995). The absence of this hump-shaped response in investment primarily reflects the weak internal propagation mechanism of the standard real business cycle model.

Typically real business cycle models are calibrated so the steady state share of investment in total output matches the mean share observed in the macroeconomic data. Consequently, by including household capital in the definition of this investment, they substantially overstate the size of this single capital good. For example, the mean share of investment in non-residential capital as a proportion of output is probably closer to 15% rather than the 27% used by Christiano & Eichenbaum (1992).[3] Of course this will probably only pose a particular problem when comparing the dynamic responses in investment to the empirical responses. In contrast, when the aim is to compare the (theoretical) dynamic responses from alternative structural models, this misspecification of the steady state share of investment will likely be of secondary importance.

Blanchard & Perotti (2002) present an alternative approach that may be used to identify exogenous changes in fiscal policy, with perhaps less emphasis on event studies. In contrast to the approach of Ramey & Shapiro (1998), Edelberg et al. (1999) and Burnside et al. (2004) who focus on event studies, they incorporate these event studies within a structural VAR approach. The results provided in Blanchard & Perotti (2002) suggest that private consumption is crowded in by government spending. They note that this will be difficult to reconcile with the standard neoclassical growth model, except under counter-factual assumptions about the path of taxation over time. In addition, they find that private investment is crowded out by government spending. As noted by Blanchard & Perotti (2002), this result might be consistent with the standard neoclassical approach in the presence of distortionary taxation (p 1331). These results imply that the empirical response of private consumption might be dependent upon the particular strategy used to identify exogenous changes in government spending.

The previous chapter has detailed a structural model in which increases in government consumption are financed by lump sum taxes. In contrast, Burnside et al. (2004) consider increases in government consumption financed by distortionary taxes on labour and physical capital. In response to the onset of a Ramey-Shapiro episode, both labour taxes and capital taxes rise in a hump-shaped manner. Burnside et al. (2004) note that the ability of the standard neoclassical model to account

[3]After accounting for household capital, Edelberg et al. (1999) calibrate their model with a steady state share of non-residential investment of approximately 15%. Alternatively, Atkeson & Kehoe (2002) suggest that this share should be approximately 11% for U.S. manufacturing.

for the stylized facts depends critically upon the assumption of lump sum taxation. They note that when the increase in government spending is financed entirely by distortionary taxation, movements in distortionary tax rates affect the timing of the response of hours. Although both their lump sum taxation and their distortionary taxation specifications have difficulty in accounting for the precise timing of how hours empirically respond to a fiscal shock, they suggest that the specification with distortionary taxation does significantly worse.

As a first step in applying the strategy of Christiano et al. (1999) and Edelberg et al. (1999), it is necessary to understand the predictions of alternative structural models to a fiscal shock. In particular, this chapter is concerned with the predictions from a structural model that allows for the accumulation of organizational capital compared to an otherwise equivalent model that ignores the accumulation of organizational capital. The simplest structure that allows such a comparison involves the presence of lump sum taxation. This assumption is not particularly troublesome if the aim is to compare the theoretical dynamic responses to an (unanticipated) fiscal shock. Provided that there are sufficient differences in the dynamic responses arising from the accumulation of organizational capital, the second step in the strategy outlined by Edelberg et al. (1999) would involve quantitatively comparing these theoretical dynamic responses to the empirical responses. Aside from a few general observations, this second step will not be addressed in this thesis and represents an important area of future research.

3.3 Solution Dynamics

This chapter studies the dynamic response of the aggregate economy, characterized by the structural economy detailed in Chapter 2, to an exogenous increase in government consumption that temporarily perturbs the aggregate economy away from its steady state. Unfortunately, the structural model that allows for the accumulation of organizational capital, outlined in the previous chapter, does not possess an analytical solution for the full dynamic path. An approximate linear solution is obtained using the now standard method of King et al. (1988a,b) and detailed in King et al. (2002). This solution is derived by linearizing the six equations characterizing the competitive equilibrium in the neighbourhood of the non-stochastic steady state.

Appendix A.3 provides a complete description of this approximate solution where the variable $\hat{m}_t$ denotes the percentage deviation of the variable m_t from its value in the non-stochastic steady state.

As discussed in the previous chapter, each member of the representative household pays the lump sum tax τ_t that is used to finance government consumption of the final good. The government is required to balance their budget each period. It is assumed that government consumption does not directly alter the marginal utility of (private) consumption or the productive stock of physical capital.

The transformed (stationary) structural model, detailed in the previous chapter, involves the level of de-trended government consumption g_t which is defined as $G_t X_t^{-\chi}$ where X_t represents the level of labour-augmenting technical progress. Here G_t denotes the untransformed level of government consumption. In the transformed economy, government consumption g_t is assumed to evolve according to the following stochastic process:

$$\ln g_t = \ln G_t - \chi \ln X_t = (1 - \rho_g) \ln \bar{g} + \rho_g \ln g_{t-1} + \zeta_{gt} \tag{1}$$

where $|\rho_g| < 1$, $\ln \bar{g}$ is the mean of $\ln g_t$ and ζ_{gt} is a serially uncorrelated process with mean 0 and standard deviation $\sigma_{\zeta g}$. By definition, the level of untransformed government consumption G_t is determined by both the transformed level of government consumption g_t and the level of technology X_t. Since the level of technology is assumed to follow a random walk with drift, movements in the level of technology have a permanent impact upon the level of government consumption G_t whilst movements in g_t have a transitory impact upon the level of government consumption. This stochastic process has the advantage that the percentage deviation of government consumption from its non-stochastic steady state value will be given by:

$$\hat{g}_t = \rho_g \hat{g}_{t-1} + \zeta_{gt} \tag{2}$$

The fiscal shocks considered in this paper represent one-time innovations to the first order autoregressive process (1) presented above. Two alternative values for the persistence of this stochastic process are considered. As shown by Aiyagari & Christiano (1992), the persistence of this process may have important implications for the aggregate effects of temporary fiscal shocks in the standard constant returns stochastic growth model. A value of $\rho_g = 0$ implies that this fiscal shock is purely temporary. A value of $\rho_g = 0.96$ will also be considered. This is the value estimated by Christiano & Eichenbaum (1992) and is contained within a 95% confidence interval around the estimate of Burnside & Eichenbaum (1996).

As noted above, recent work by Ramey & Shapiro (1998), Edelberg et al. (1999) and Burnside et al. (2004) associated with identifying fiscal policy shocks with exogenous changes in military purchases suggests that modelling government consumption as an $AR(1)$ process may be inappropriate. Instead, Edelberg et al. (1999) suggest that $\ln g_t$ should be assumed to evolve according to a univariate moving average representation whose coefficients are given by an estimated impulse response function for a Ramey-Shapiro episode. Although the $AR(1)$ process (1) should not be used to assess the empirical properties of the structural model, it may still be used to investigate dynamic properties of the structural model. In particular, it may be used to investigate the effect of allowing for the accumulation of organizational capital upon the transitional dynamics of an otherwise standard stochastic growth model, in response to an (exogenous) fiscal shock. For this reason, this chapter will restrict attention to the dynamic responses associated with an exogenous fiscal shock that evolves according to the $AR(1)$ process outlined above.

It is clear from Appendix A.3 that the value of g/y in the non-stochastic steady state needs to be specified prior to studying the transitional dynamics. A value of $g/y = 0.177$ is used in all versions of the model. This value corresponds to the mean ratio of g/y in the U.S. data over the period 1955:4 to 1983:4 reported by Christiano & Eichenbaum (1992).[4] Although this value for g/y is slightly lower than the value suggested by Baxter & King (1993) and Edelberg et al. (1999), small changes in the value of this ratio have very little impact upon the dynamic response of key macroeconomic variables to a fiscal shock.

The set of linearized equations detailed in Appendix A.3 will have a unique (rational expectations) solution provided the dynamics satisfy certain conditions. In particular, this requires that the roots of the fundamental difference equation, de-

[4]Following Baxter & King (1993), this period might be characterized by a permanent increase in g/y accompanied by large, temporary movements in g/y.

tailed in King et al. (2002), be such that the number of eigenvalues less than one in absolute value is exactly equal to the number of state variables. Similarly there is an appropriate restriction when the roots are characterized by complex conjugate pairs. Since organizational capital is treated as an input in the production technology, the accumulation of production experience might be associated with a production technology that exhibits increasing returns to scale. As shown by Benhabib & Farmer (1999), these conditions need not necessarily hold in the presence of increasing returns to scale. However, the existence of indeterminate equilibria requires sufficiently large increasing returns to scale.[5] The calibration strategy, detailed in the previous chapter, imposes constant or mildly increasing returns to scale in physical capital and labour so that the sum $\alpha + \theta$ is close to unity. Recall that the returns to scale of the production technology will be given by $(\alpha + \theta)/(1 - \varepsilon)$. In the following sections, parameter values for ε will be chosen so that the returns to scale of the production technology are not sufficiently large. In this case the set of (equilibrium) linearized equations will have a unique rational expectations solution in the neighbourhood of the non-stochastic steady state.[6]

The linearized system presented in Appendix A.3 represented a coupled dynamical system. Within the set of unique rational expectations equilibria, the fundamental difference equation might possess either real roots or pairs of complex roots. Despite this, attention will be restricted to stable competitive equilibria in which the roots of the fundamental difference equation, detailed in King et al. (2002), are all real. Once again this does not imply that (locally) stable competitive equilibria in the neighbourhood of the non-stochastic steady state characterized by complex roots are not worthy of consideration. This decision to exclude complex roots is primarily motivated by a desire to limit the range of appropriate values for the structural parameters, particularly the organizational capital parameters, to a reasonable size. This restricted parameter set involves sufficiently low values for the scale elasticity,

[5]Here indeterminacy refers to the existence of multiple rational expectations equilibria all of which converge to the steady state.

[6]This should not be interpreted as implying that the existence of indeterminate equilibria is a trivial consequence that should be avoided. There is an important literature that exploits the existence of an indeterminate set of competitive equilibria to study the propagation mechanism in business cycle models. Benhabib & Farmer (1999) provide a survey of this literature and Guo (2004) studies fiscal shocks in the presence of indeterminate equilibria.

a value well below the level needed to induce local indeterminacy in the models of Devereux et al. (1996) and Benhabib & Farmer (1994).

An implication of restricting the degree of aggregate returns to scale is that (private) consumption will never increase following a temporary fiscal shock. Devereux et al. (1996) study the joint hypothesis of increasing returns to scale and monopolistic competition in a one-sector real business cycle model. They show that, in response to a positive government spending shock, output, consumption, investment, employment and real wages might increase provided the returns to scale are sufficiently large. The number of intermediate goods producers is endogenously determined by a zero profit condition so that the productivity of intermediate goods producers depends positively on the number of intermediate goods produced. Consequently, there will be a divergence between the production technology of individual producers and the social technology. As shown by Guo (2004), these results require the structural economy to exhibit local indeterminacy in the neighbourhood of the steady state. As noted above, these results are difficult to reconcile with the stylized facts associated with the empirical response to a government spending shock.

Following Guo (2004), the model of Benhabib & Farmer (1994) with internal increasing returns to scale without free entry will also produce an aggregate production technology consistent with the social technology in Devereux et al. (1996). Therefore, it is the existence of local indeterminacy that is required to generate these results, rather than the assumption of free entry. Consequently, when the degree of (internal) increasing returns to scale is sufficiently small, the standard one sector real business cycle model with monopolistic competition will not generate dynamic responses that are considerably different than those implied by the model with perfect competition and constant returns to scale.

This can be seen by comparing the linearized first order conditions for the model that ignores organizational capital to the linearized first order conditions for the standard one sector perfect competition real business cycle model. Since the demand parameter μ does not appear (directly) in the linearized equations, presented in Appendix A.3, it can be shown that these linearized equations will take the same form as those implied by the planning solution in the standard model. However, with $\mu > 1$, the steady state k/y ratio for the model with imperfect competition will be lower than the k/y ratio in the planning solution, holding all else constant. Consequently, imperfect competition affects the coefficients of the linearized system for the model that ignores organizational capital, compared to the planning solution. Provided the steady state in the decentralized model with monopolistic competition is not considerably different than the steady state in the planning solution, the transitional dynamics in the monopolistic competition model will be approximately equivalent to those implied by the planning solution. This result essentially arises because the degree of returns to scale is directly linked to the steady state markup (which is equivalent to the demand parameter μ) so that restricting the returns to scale also restricts the magnitude of demand parameter.

Given this, it is natural to consider whether the dynamic responses in the model that allows for the accumulation of organizational capital might be approximately equivalent to the dynamic responses in the social planner's solution provided in Cooper & Johri (2002). As shown in the previous chapter, the accumulation of organizational capital in the presence of monopolistic competition implies the steady state k/y ratio will differ from that implied by the planning solution of Cooper & Johri (2002) for several reasons. Firstly, because production units face a demand constraint the market prices in the decentralized solution will not coincide with the shadow prices in the planning solution. This has a similar effect upon the coefficients of the linearized system as that identified above for the model that ignores organizational capital. However, the value of an additional unit of organizational capital in the planning solution is valued in terms of the marginal utility of consumption whereas in the decentralized solution this additional unit is valued in terms of marginal profit. This differing valuation not only affects the magnitude of the k/y ratio in the steady state but will also affects the transitional dynamics

Beyond these observations, this chapter is not concerned with comparing the planner solution of Cooper & Johri (2002) to an appropriately specified decentralized model. Rather, it is concerned with evaluating the implications of allowing for the accumulation of organizational capital upon the dynamic response of the aggregate economy to exogenous disturbances that temporarily perturb the aggregate economy away from its steady state. Importantly, by concentrating upon the accumulation of organizational capital by production units, it seeks to evaluate whether the endogenous propagation mechanism identified by Cooper & Johri (2002) depends critically upon who is accumulating this organizational capital. This evaluation is achieved by comparing the transitional dynamics of a structural model that allows for the accumulation of organizational capital by production units to a model that ignores the accumulation of organizational capital.

3.4 A Temporary Change in Government Consumption

This section considers the transitional dynamics of the structural model of organizational capital in response to a temporary shock to government purchases equal to one percent of government consumption in the non-stochastic steady state.

Appendix A.3 contains a description of the approximate linear solution for three alternative models—a structural model in which organizational capital is accumulated according to a log-linear technology, a structural model in which organizational capital is accumulated according to linear technology, and a model that ignores the accumulation of organizational capital. In order to evaluate the endogenous propagation mechanism associated with the accumulation of organizational capital, the transitional dynamics of the organizational capital model with a log-linear accumulation technology will be compared to a model that ignores organizational capital.[7]

It is clear from Appendix A.3 that this requires values of the steady state magnitudes of g/y, k/y and c/y. In addition, values for the structural parameters β, δ, α, θ and ψ_x are also required. For the organizational capital model, the structural parameters ε and γ will need to be specified. The previous chapter has detailed a calibration strategy for specifying these required parameters.

This calibration strategy implies that the steady state values of k/y, c/y and i/y for the organizational capital model will be identical for alternative values of ε and γ. This does not imply that the alternative values of ε and γ produce identical steady states. In particular, the steady state markup will depend upon the assumed value of the sum $(\alpha + \theta)$ and a residual profit share $[1 - lsh + ksh \exp(-\chi\psi_x)]$. Therefore, the steady state of the organizational capital model must be described with reference to particular assumptions regarding both $(\alpha + \theta)$ and the residual profit share.

[7]Later, the transitional dynamics of the model characterized by a log-linear technology will be compared to those for a linear technology.

Despite this, for a given value of the sum $(\alpha + \theta)$ and residual profit share, alternative values of ε and γ will produce the same steady state markup. In this case, alternative values of ε and γ will be associated with the same steady state. This is particularly useful when comparing the transitional dynamics of the organizational capital model, for alternative value of ε and γ. Any differences in the transitional dynamics may be attributed to effect of the values of these organizational capital parameters upon the out of steady state behaviour of the organizational capital model.

After specifying the sum $(\alpha + \theta)$ and the residual profit share, the calibration strategy detailed in the previous chapter provides a method for calculating the implied values of α, θ that will be consistent with the mean k/y observed in the aggregate data. The model that ignores the accumulation of organizational capital is then calibrated using these values of α and θ. Since the terms ψ_2 and ψ_3 in Appendix A.3 depend upon β, δ, $\chi\psi_x$ which are assumed to be the same for both models, the coefficients ψ_2 and ψ_3 will be the same for both the organizational capital model and the model that ignores organizational capital. However, the steady state k/y, c/y and i/y ratio for the organizational capital model will be different than the steady state k/y, c/y and i/y ratio for model that ignores organizational capital. As suggested in the previous chapter, these differences essentially reflect the misspecification associated with ignoring the accumulation of organizational capital. Therefore, the difference in the transitional dynamics for the organizational model compared to those for the simple model will reflect both a different steady state and different dynamic behaviour outside the steady state.

As discussed in the previous chapter, the term χ will depend upon ε so that χ for the model with organizational capital will generally differ to that for the model that ignores organizational capital, even when the production parameters α and θ are the same. The calibration strategy assumes that the term $\chi\psi_x$ remains the same regardless of the values of these production technology parameters by making the (implied) growth rate in technology (ψ_x) also a function of these production technology parameters. This assumption implies that both the organizational capital model and the model that ignores organizational capital have the same steady state growth rate in the level of output.

For the purposes of comparing the simple model with the organizational capital model, results will be presented for the case where $(\alpha+\theta) = 1$ and a residual profit share of 5%. The restriction $(\alpha+\theta) = 1$ is primarily motivated by two considerations. Firstly, the existing empirical evidence suggests that the aggregate production technology, ignoring the accumulation of organizational capital, exhibits approximately constant returns to scale. Secondly, with $(\alpha+\theta) = 1$, the desire to restrict the degree of returns to scale in the organizational capital model, implies that several values of ε might be considered. Since this section compares the organizational capital model (with a log-linear accumulation technology) to a model that ignores organizational capital, results are presented for a given value of γ. Specifically, the transitional dynamics of the simple model are compared to those for organizational capital with $\gamma = 0.2$ and alternative values of ε.[8] The calibrated values of the structural parameters for both the simple model and the organizational capital model are provided in Table 3.1.

3.4.1 A Transient Government Consumption Shock

In order to gain some intuition for the effect of allowing for the accumulation of organizational capital it is useful to compare the dynamic responses of these two model economies to a one time (unanticipated) shock equal to 1% of the level of government consumption in the non-stochastic steady state. Unfortunately, the magnitude of these dynamic responses, in the periods immediately following the shock, is so small that any differences in the dynamic responses for the two model economies will be very difficult to identify from a visual examination of the implied dynamic responses. This is because the purely transitory fiscal shock represents a negligible shock to the permanent income of the representative agent. Table 3.2 describes the dynamic responses for the first eight periods following a purely transient government shock for a given value of $\varepsilon = 0.10$.

It is important to emphasize that the magnitude of these dynamic responses depend critically upon the indivisible labour representation of household preferences. In particular the representative agent has preferences that are linear in leisure which implies an infinite λ-constant elasticity of labour supply. As noted by King & Rebelo (1999, p.978) this implies that the demand side of the labour market will determine the

[8] Later, the transitional dynamics will be studied for alternative values of γ.

(optimal) quantity of employment and work effort in the indivisible labour economy.

Consider the dynamic responses for the model that ignores organizational capital. An increase in the level of government consumption raises the present value of the representative household's taxes and lowers its permanent income. Since government consumption does not contribute to either production or utility, in the presence of lump sum taxes, an increase in g_t represents a negative wealth effect. In the absence of any changes in the real wage, the negative wealth effect associated with the fiscal shock will induce a reduction in consumption and a positive (desired) labour supply response. Since the employment response will be determined by the demand side of the labour market, equilibrium in the labour market requires a reduction in the real wage and a corresponding increase in the demand for labour. This is reflected in the linearized first order conditions for the indivisible labour economy where the percentage deviation of consumption from its steady state value is identical to the percentage deviation in the real wage.[9] The net consumption response in the impact period will reflect the combination of this negative wealth effect and the response in the real wage necessary to produce the desired employment response.

Since the stock of physical capital is predetermined, this increase in employment will raise output in the impact period. The representative household desires to smooth consumption over time. Facing relatively small changes in employment, the real wage rate, and the real interest rate, the representative agent finds it optimal to achieve this consumption smoothing by reducing investment in the period of the small, transitory income shock.[10]

Since the percentage change in consumption must be identical to the percentage change in the real wage, employment does not immediately return to its steady state value because the smoothing of consumption implies the real wage will remain below its steady state value. The reduction in investment, in the impact period will produce a reduction in the stock of physical capital, relative to its level in the non-

[9]Note that this response of employment must exceed that for an equivalent model with a finite intertemporal labour supply elasticity. With a reduced substitution effect, the representative household would find it optimal to reduce consumption by a relatively larger amount and varying hours of work by a relatively smaller amount. In this case, the real wage will fall by a relatively smaller amount, compared to the indivisible labour economy.

[10]This reduction in investment in response to a purely transitory shock is a common result for the standard model and has been identified by Aiyagari & Christiano (1992).

stochastic state. Since the rental price of capital will depend inversely on the stock of physical capital, plants will find it optimal to substitute labour for physical capital. This produces a positive, yet reduced employment response in the period immediately following the fiscal shock.[11] This relative movement in factor prices induces an extremely small reduction in output, relative to its steady state value. In the presence of consumption smoothing, this small employment response in time $t+1$ induces an optimal slight increase in investment above its steady state level. In subsequent periods, investment, the stock of physical capital, employment and output smoothly approach their non-stochastic steady state values.

An examination of Table 3.2 reveals that the dynamic responses for the model characterized by a log-linear accumulation technology are more or less qualitatively similar to those for the simple model that ignores the accumulation of organizational capital. However, there are some differences in the dynamic responses of the simple model, relative to the organizational capital model that are worth further exploration.

Firstly, in the impact period, there is a reduced (negative) response in both consumption and investment and a lower impact period response in employment and output, relative to the model that ignores organizational capital. In the periods immediately following the shock, the responses of investment, employment and output exceed those for the simple model.

The dynamic responses for the organizational capital model will differ from those implied by the simple model for two reasons. Firstly, the steady state in the organizational capital model will differ from the steady state in the model that ignores organizational capital. For given values of α and θ, the steady state k/y ratio in the organizational capital will exceed that implied by the model that ignores organizational capital. This affects the coefficients in the linearized equations provide in Appendix A.3.

Secondly, the dynamic responses will differ because the accumulation of organizational capital implies that plant behaviour is forward looking and introduces a dynamic structure into the plant maximization problem that does not exist in the simple model. Just as the household multiplier λ_t^h governs the optimal allocation

[11] Since the shock to government consumption is transitory, there are no negative wealth effects in the periods following the shock.

of wealth across periods, the plant multiplier λ_t^f controls the optimal allocation of output across periods. In particular, the multiplier λ_t^f measures the value of an additional unit of organizational capital, in terms of marginal profits, so that organizational capital will be accumulated up to the point where the value of an additional unit of organizational capital today is equal to the discounted value of this unit of organizational capital next period.

Consider the case where the employment impact response for the organizational capital model is identical to that for simple model. Since the stocks of physical capital and organizational capital are predetermined, this will imply that the output impact response will be identical in both models. This will produce a percentage deviation in the stock of organizational capital for time $t+1$ according to $\hat{z}_{t+1} = \alpha\gamma\,\hat{H}_t$. An examination of Table 3.2 reveals that this percentage deviation in the organizational capital stock will exceed the (optimal) percentage deviation in z_{t+1}. This is primarily because there is diminishing marginal productivity of organizational capital associated with both curvature in the production technology and the (log-linear) accumulation technology. Consequently, the (optimal) impact response in output will be lower, compared to the simple model in order to deliver the optimal response in organizational capital along the transition path to the steady state. This optimal organizational capital response is determined by the evolution of the plant multiplier along the transition path. With the stocks of physical capital and organizational capital predetermined, this implies that the employment impact response, will also be lower, compared to the simple model.

Despite this lower impact output response, the accumulation of organizational capital will be associated with a larger output response in the periods following the purely transient government shock, compared to the simple model. Fundamentally, relative to the simple model, the accumulation of organizational capital generates a positive income effect for households. In the presence of consumption smoothing, households will find it optimal to spread this temporary (positive) income effect over several periods. Therefore, for the organizational capital model, the impact period consumption response will reflect both the negative wealth effect associated with the government shock and the anticipated positive wealth effect associated with the accumulation of organizational capital. As shown in Table 3.2, the consumption response in the impact period will be less negative, compared to the simple model. Recall that the assumption of indivisible labour implies that the percentage deviation of consumption from its steady state value will be identical to the percentage deviation in the real wage. Ultimately, the dynamic response in consumption will reflect a combination of these income effects and the response in the real wage needed to produce the desired employment response associated with the (optimal) dynamic response in organizational capital.

Since the accumulation of organizational capital alters the (optimal) transition path for output, it will also alter the optimal dynamic responses in physical capital and employment. In particular, the accumulation of organizational capital will alter the (desired) input combinations of physical capital, employment and organizational capital along the transition path. Through movements in factor prices, this will affect consumption and investment along the transition path to steady state. The response of employment in the impact period, which affects the response in the real wage and the real interest rate, will be such that production units will be able to achieve their desired input of physical capital in the periods following the shock. Consequently, relative to the simple model, the organizational capital model will be characterized by a (less) negative impact period response in investment.

There are two very important results arising from this analysis of the dynamic responses for the organizational capital model. Firstly, a purely transitory fiscal shock is able to generate persistent increases in output, above its steady state value, for several periods following the shock. Secondly, the behaviour of key macroeconomic variables outside the non-stochastic steady state is somewhat more complicated than the simple model that ignores the accumulation of organizational capital. Unfortunately, these effects arising from a one time fiscal shock are extremely small and these differential output effects in the periods following the shock, are approximately zero. In order to explore further the implications of ignoring the accumulation of organizational capital it is worthwhile to consider a more persistent shock to government consumption that lasts for more than a single period. In addition, these dynamic responses associated with a persistent government shocks facilitate a comparison, at least qualitatively, with the empirical dynamic responses identified above.

3.4.2 A Persistent Government Consumption Shock

Figures 3.1 to 3.3 compare the dynamic responses to a persistent fiscal shock for a model that ignores the accumulation of organizational capital to a model characterized by a log-linear accumulation technology, for given value of $\gamma = 0.2$. Both the model that allows for the accumulation of organizational capital and the model that ignores organizational capital are calibrated with the same values for the structural parameters. The values for these structural parameters are given in Table 3.1. Consequently, Figure 3.1 uses the values detailed in columns 1 and 4 of Table 3.1. Similarly, Figure 3.2 uses the values detailed in columns 2 and 5 of Table 3.1 and Figure 3.3 uses the values detailed in columns 3 and 6 of Table 3.1

Figure 3.1 plots the dynamic responses for these two models using a low value of $\epsilon = 0.05$. In this case, the label "no org k" refers to the dynamic responses for the model that ignores organizational capital. The label "low epsilon = 0.05" refers to the dynamic responses for the organizational capital model. Similarly Figure 3.2 plots the dynamic responses for the two models using a medium value of $\epsilon = 0.10$ where the label "medium epsilon = 0.10" refers to the dynamic responses for the organizational capital model. Finally, Figure 3.3 plots the dynamic responses for the two models using a high value of $\epsilon = 0.15$ where the label "high epsilon = 0.15" refers to the dynamic responses for the organizational capital model and the label "no org k" refers to the dynamic responses for the model that ignores organizational capital.

In this case of a persistent a shock to government consumption, an increase in g_t represents a considerable decline in the permanent income of the representative agent. Relative to the case of a purely transitory fiscal shock, the dynamic responses are governed by this larger negative wealth effect associated with the persistent yet temporary increase in government consumption.

The dynamic responses implied by the standard constant returns to scale, perfectly competitive economy are well understood.[12] An examination of Figure 3.1 reveals that the dynamic responses for the model that ignores organizational capital are, at least qualitatively, consistent with the empirical impulse responses associated with the onset of a Ramey-Shapiro episode, identified by Edelberg et al. (1999) and

[12]Baxter & King (1993), Edelberg et al. (1999) and Burnside et al. (2004) provide some intuition for these dynamic responses along the transition path to the non-stochastic steady state.

Burnside et al. (2004). A persistent (unanticipated) increase in government consumption is associated with an increase in employment, output, and investment with a fall in both the real wage and consumption.

One problem in comparing the dynamic responses presented in Figures 3.1 to 3.3 with the dynamic responses, for the standard real business cycle model, provided in Burnside et al. (2004) is that they involve quite different stochastic processes for exogenous government consumption. In particular, Burnside et al. (2004) present the dynamic responses for the case where government purchases evolve according to a univariate moving average representation whose coefficients are given by the estimated dynamic response function for a Ramey-Shapiro episode. This dynamic response is characterized by a large persistent hump-shaped rise in government purchases. In contrast, the dynamic response of government consumption in Figures 3.1 to 3.3 is characterized by an $AR(1)$ stochastic process.

The dynamic response of employment in the benchmark specification of Burnside et al. (2004) with Hansen-Rogerson preferences and lump sum taxation exhibits a hump-shaped response in employment, consistent with the empirical dynamic response in employment associated with the onset of a Ramey-Shapiro episode. However, the results presented in Figures 3.1 to 3.3 do not exhibit this hump-shaped response in employment. This result would be consistent with the critique of Cogley & Nason (1995) in which the output (and employment) dynamics in this simple model, which ignores organizational capital, reflect the impulse dynamics. Since this chapter is concerned with evaluating the (internal) propagation mechanism associated with the accumulation of organizational capital, it seems appropriate to restrict attention to the case where the government purchases does not exhibit a hump-shaped response.

It is interesting to note that the dynamic responses of consumption and investment in the benchmark specification of Burnside et al. (2004) do not exhibit a hump-shaped pattern, despite the hump-shaped response in government purchases. Burnside et al. (2004) note that, relative to the empirical responses, the standard model tends to overstate the decline in consumption and overstate the increase in investment.

As noted by Edelberg et al. (1999), a positive shock to government consumption induces a persistent rise in non-residential investment. In this case, the failure of the standard model may be reinterpreted as a failure to generate a dynamic response in non-residential investment that is characterized by a hump-shaped response. In addition, Edelberg et al. (1999) suggest that the empirical responses in non-durable consumption expenditures and household capital are quite small so that the standard model would continue to overstate the fall in consumption expenditures. However, the quantitative significance of these apparent failures cannot be determined in the present context.

In what follows the dynamic responses for both the model that ignores organizational capital and the model that allows for the accumulation of organizational capital will be assessed as to their ability to generate dynamic responses that are qualitatively consistent with the empirical responses. Primarily, these dynamic responses should exhibit a hump-shaped increase in output, employment and non-residential investment and a hump-shaped decrease in real wages.

The intuition for the dynamic responses to a persistent shock for both the organizational capital model and the model that ignores organizational capital is similar to that associated with a purely transitory shock. Comparing Table 3.2 with Figures 3.1 to 3.3 confirms the result presented in Aiyagari & Christiano (1992)—the employment and output effects of persistent increases in government consumption always exceed those of temporary increases.

However, there are some important differences in the dynamic responses of the organizational capital model associated with a persistent shock, relative to those associated with a purely transitory shock. Recall that in the case of a purely transitory fiscal shock, organizational capital will immediately increase, relative to its steady state level and then decline monotonically towards this steady state level. The peak response in organizational capital will occur in the period immediately following the transitory shock. In contrast, in the case of a persistent fiscal shock, organizational capital will be characterized by a hump-shaped response. Figures 3.1 to 3.3 reveal that the peak response in organizational capital will occur several periods after the onset of this persistent shock. Fundamentally, this hump-shaped response in organizational capital implies that the peak response in organizational capital will not correspond to the peak response in government consumption. It is this hump-shaped response in organizational capital that drives the differences in the dynamic responses for the organizational capital model, relative to the model that ignores organizational capital.

As noted above, the dynamic responses in the organizational capital model are governed by the dynamic response of the plant multiplier λ_t^f which controls the optimal accumulation of organizational capital and the allocation of output across time periods, in response to the fiscal shock. In particular, organizational capital will be accumulated up to the point where the value of an additional unit of organizational capital today, in terms of marginal profit, is equal to the discounted value of this organizational capital tomorrow.

An examination of Figures 3.1 to 3.3 reveal that, at least initially, it is optimal to accumulate more organizational capital, relative to its steady state level. The existence of diminishing marginal productivity of organizational capital associated with both curvature in the production technology and the accumulation technology implies that, at some point, further increases in the stock of organizational capital will no longer be optimal. At this point, it will be optimal for the stock of organizational capital to smoothly approach its steady state level. The dynamic response for output will be such that organizational capital follows this optimal transition path to the steady state.

Since organizational capital is a productive factor of production, the accumulation of organizational capital will also alter the optimal responses in employment and physical capital. In particular the accumulation of organizational capital along the transition path will alter the (desired) input combinations of labour and physical capital. Consequently the responses in employment and physical capital will be such that they will represent the profit maximizing quantities associated with the transition path of organizational capital. Through movement in factor prices, this will affect consumption, employment, and investment along the transition path.

In addition to the negative income effect associated with the persistent increase in government consumption, Figures 3.1 to 3.3 show that the accumulation of organizational capital also generates a positive income effect, net of movement in factor prices, along the transition path to the steady state. In the presence of consumption smoothing, the representative household finds it optimal to spread this income effect over several periods. Consequently, all else equal, the optimal consumption response will be less negative for the organizational capital model, compared to the simple model. Recall that the assumption of indivisible labour implies that the percentage deviation of consumption from its steady state value will be identical to the percentage deviation in the real wage. Ultimately, the dynamic response in consumption will reflect a combination of these income effects and the response in the factor prices needed to produce the desired employment response associated with the (optimal) dynamic response in organizational capital.

Ultimately, the response in investment will be such that it allows production units to rent its desired inputs of physical capital and labour along the transition path while at the same time allowing households to achieve their desired smoothing of consumption. In the impact period investment will be given by:

$$\hat{i}_t = \alpha \frac{y}{i} \hat{H}_t - \frac{c}{y}\frac{y}{i} \hat{c}_t - \frac{g}{y}\frac{y}{i} \hat{g}_t$$

Figures 3.1 to 3.3 indicate that the optimal employment response in the impact period will be lower than that associated with the model that ignores organizational capital. With a less negative consumption response, it must be true that the investment response in the impact period must be lower for the organizational capital model. At some point, along the transition path, production units desire to rent more physical capital than would be generated in the model that ignores organizational capital. Consequently, at some point, investment must exceed that in this simple model.

The most striking feature of the dynamic responses for the organizational capital model is the existence of a hump-shaped dynamic response for investment that does not arise in the model that ignores organizational capital. Intuitively, the accumulation of organizational capital alters the desired physical capital input along the transition path. The dynamic response of investment is such that production units will be able to rent their desired inputs of physical capital along the transition path while at the same time allowing household's to achieve their desired smoothing of consumption.

Of course, the accumulation of organizational capital is not the only mechanism capable of generating a hump-shaped response in investment. Burnside et al. (2004) introduce adjustment costs in investment which penalize changes in the level of investment. Their specification of investment adjustment costs alters the accumulation technology for physical capital. Alternatively, Edelberg et al. (1999) generate a hump-shaped response in non-residential investment by introducing an additional state variable that reflects the accumulation of household capital. In contrast to the standard model, households receive a utility benefit from units of the non-durable consumption good and the stock of household capital.

Both Burnside et al. (2004) Edelberg et al. (1999) represent the choice problem of the representative agent through a stochastic dynamic programming problem solved by a planner. It is clear that these alternative mechanisms introduce an additional dynamic structure into this planner's problem. As such, the general equilibrium effects of these alternative mechanisms might be qualitatively similar, at some level, to the general equilibrium effects of allowing for the accumulation of organizational capital. This becomes clear when the first order conditions from these models are compared to the first order conditions in the social planner's problem in Cooper & Johri (2002). This suggests that the existence of a hump-shaped response in investment requires an additional dynamic structure beyond that provided in the standard real business cycle model. The accumulation of organizational capital provides one source of this additional dynamic structure.

Generally, compared to the simple model, the accumulation of organizational capital generates a (slightly) lower dynamic response in consumption. However, this difference is probably not significant. In contrast, the model of Burnside et al. (2004) with investment adjustment costs, and without habit persistence in consumption, produces a dynamic response in consumption that is substantially larger than that implied by the empirical responses. This suggests that, the existence of a hump-shaped response in investment need not imply a reduced consumption response.

An examination of Figures 3.1 to 3.3 reveals that the dynamic response for real wages will not exhibit a hump-shaped response for either the model that ignores organizational capital and the organizational capital model. This probably arises because the indivisible labour representation of preferences implies the percentage deviation in the real wages will always be identical to the percentage deviation in consumption. However, it can be shown that an alternative representation of preferences with a finite λ-constant labour supply elasticity will also produce a dynamic response in the real wage that does not exhibit a hump-shaped pattern. These alternative preferences simply allow for the dynamic response in the real wage to differ from the dynamic response in consumption. As suggested by Burnside et al. (2004), it might be possible to generate a hump-shaped response in real wages in the presence of distortionary taxation. Consequently, the absence of a hump-shaped response in real wages probably reflects the assumption of no distortionary taxes on labour supply.

Finally, it is worth noting that the accumulation of organizational capital implies a difference between the percentage response in the real wage and the percentage response in average labour productivity, along the transition path to the steady state. In contrast to the simple model, the share of labour in total revenues need not be constant. Although the results are not shown in Figures 3.1 to 3.3, allowing for the accumulation of organizational capital, a persistent increase in the level of government consumption generates an extremely small hump-shaped decrease in the labour share. As noted by Eichenbaum & Fisher (1998), the empirical response in real wages, induced by the onset of a Ramey-Shapiro episode, need not necessarily be equivalent to the empirical response in average labour productivity. Although real wages unambiguously fall in response to a Ramey-Shapiro episode, the results for the response in average labour productivity are less clear. This provides some extremely limited evidence that the onset of a Ramey-Shapiro episode might elicit a response in the labour share. However, it is unclear whether the implied dynamic response in the labour share for the organizational capital model will be consistent with this empirical response.

It is clear from Figures 3.1 to 3.3 that the dynamic responses for the organizational capital model will depend upon the value of ε. In particular, larger values of ε affect the (optimal) accumulation of organizational capital along the transition path. This affects the dynamic responses for many macroeconomic variables of interest. Importantly, a sufficiently large value of ε will be characterized by a hump-shaped response in output. Since the dynamic responses for the model that ignores organizational capital will not be characterized by this hump-shaped response, it is worthwhile exploring in some detail how alternative values of ε affect the dynamic responses of the organizational capital model.

3.4.3 Dynamic Responses and Alternative Values for the Organizational Capital Parameters

The value of ε, for a given value of γ, will affect the dynamic responses for both the simple model and the organizational capital model. Firstly, the steady state of the model that ignores organizational capital will differ from the steady state of the model with organizational capital. These differences in the steady state values will depend upon the value of ε. For example, the difference between the k/y ratio in the simple model and the k/y ratio in the organizational capital becomes increasingly large for larger values of ε, for a fixed value of α, θ, μ, and $\chi\psi_x$. Intuitively, larger values of ε are associated with a greater degree of misspecification in the simple model. This affects the coefficients in the linearized system for the simple model provided in Appendix A.3. Despite this, the effect of alternative values of ε upon the dynamic responses of the simple model is extremely small.

The organizational capital model is calibrated so that alternative values of ε have no effect upon the steady state values in the organizational capital model. Consequently, the impact of larger values of ε is fully reflected in the dynamic transition to the steady state. An examination of Appendix A.3 reveals that alternative values of ε might have several effects upon the dynamic responses for the organizational capital model. Firstly, larger values of ε raise the marginal product of organizational capital in the production technology. For a given value of α and θ, this implies that a larger value of ε raises the returns to scale of the production technology. Secondly, larger values of ε raise the magnitude of the coefficient associated with the contribution of the existing stock of organizational capital to the future stock of organizational capital. Specifically, for a given value of γ, larger values of ε lower the effective depreciation rate of organizational capital. This suggests that the dynamic structure associated with the accumulation of organizational capital will become relatively more important for larger values of ε such that current period output decisions will have a more persistent impact upon future productivity, relative to lower values of ε. Generally, the scale effect associated with larger values of ε cannot be studied without also studying the accumulation of organizational capital.

These effects associated with alternative values of ε are reflected in the optimal transition path of the plant multiplier which governs the optimal accumulation of organizational capital and the allocation of output across periods. The dynamic responses associated with alternative values of ε and a value of $\gamma = 0.2$ are summarized in Figures 3.4 and 3.5. Larger values of ε will be associated with a larger peak response in the percentage deviation in organizational capital. In addition, the emergence of this peak response will occur relatively later along the transition path to the steady state. For example, the peak response in organizational capital will occur approximately 11 periods after the onset of the fiscal shock when $\varepsilon = 0.05$. In contrast, this peak response will occur approximately 13 periods after the shock for a value of $\varepsilon = 0.15$. In conjunction with a lower effective depreciation rate of organizational capital associated with a larger value of ε, it is clear from Figures 3.4 and 3.5 that a larger value of ε will be associated with a prolonged deviation of organizational capital, employment, physical capital and output from their steady state values along the transition path.

There are also some important differences in the dynamic responses along the transition path associated with alternative values of ε. For larger values of ε, this optimal transition path involves an initially lower (positive) percentage deviation in organizational capital from its steady state value. Consequently, larger values of ε will be associated with a lower percentage deviation in output and the (desired) inputs of labour and physical capital. Note that the difference in the organizational capital response during these early periods associated with alternative values of ε is quite small. Eventually larger values of ε will be associated with a relatively larger percentage deviation in organizational capital supported by a relatively larger percentage deviation in the labour and physical capital inputs. However, this switch to a larger percentage deviation in organizational capital, output, employment and physical capital will not occur at the same time. This is because, along the transition path, the accumulation of organizational capital alters the optimal input combinations of labour, physical capital, and organizational capital used to produce output.

In the presence of consumption smoothing, any income effects associated with the fiscal shock and the subsequent accumulation of organizational capital will be spread over many periods. More importantly, consumption smoothing implies that the representative household will find it optimal to adjust consumption in the impact period in expectation of these future income effects. Therefore, larger values of ε will be associated with a less negative dynamic response in consumption.

Consistent with the initially lower (desired) inputs of labour and physical capital associated with a larger value of ε, the investment response will be lower, for larger values of ε in the early periods of the transition path to the steady state. Denoting percentage deviations associated with a low value of ε by L and those associated with a high value of ε by H, the difference in the investment response for the impact period may be written as:

$$\hat{i}_t^H - \hat{i}_t^L = \frac{\alpha}{(i/y)}\left[\hat{H}_t^H - \hat{H}_t^L\right] - \frac{(c/y)}{(i/y)}\left[\hat{c}_t^H - \hat{c}_t^L\right]$$

Since larger values of ε will be associated with a lower impact response in employment and a less negative impact response in consumption, it is clear that the impact response in investment must be lower for the larger values of ε. For sufficiently large values of ε, it may be optimal to reduce investment below its steady state value in the impact period. Intuitively, provided the (desired) percentage deviation in the physical capital input associated with larger values of ε is sufficiently low, it may be optimal to reduce investment below its steady state value in the impact period.

An examination of Figures 3.4 and 3.5 reveals that larger values of ε will be associated with a (small) initially lower response in physical capital followed by an eventual larger response in physical capital. Although the results are not shown in Figures 3.4 and 3.5, the optimal transition path associated with a larger value of ε will be characterized by a delayed peak response in physical capital. For example, when $\varepsilon = 0.05$, the peak response in physical capital will occur 26 periods after the persistent government shock. In contrast when $\varepsilon = 0.15$, this peak response will occur 31 periods after the shock. The response of investment along the transition path will need to be consistent with this optimal response in physical capital. The results in Figures 3.4 and 3.5 reveal that, for larger values of ε, the optimal investment response will be characterized by a lower impact response, and a larger and delayed peak response. It is clear that the hump-shaped response in investment is relatively more pronounced for larger values of ε.

Of course, this result is expected. Larger values of ε suggest that the dynamic structure associated with the accumulation of organizational capital will become relatively more important so that current period output decisions will have a more persistent impact upon future productivity, relative to lower values of ε. Since the hump-shaped response in investment arises because the accumulation of organizational capital implies that production units are forward looking, it is expected that this hump-shaped response will become more pronounced when the dynamic structure associated with the accumulation of organizational capital becomes relatively more important.

It is clear from Figures 3.4 and 3.5 that a sufficiently large value of ε will generate a hump-shaped response in output. The impact of larger values of ε upon the (optimal) transition path for organizational capital will be such that the peak response in output will not occur in the impact period. Intuitively, for sufficiently large values of ε, the optimal transition path will involve a delayed peak response in organizational capital which is reflected in a delayed peak response in output. Note that, for a value of $\gamma = 0.2$, this delayed output response is quite small. For example, for $\varepsilon = 0.10$, the peak response in output occurs approximately the second period following the shock and for $\varepsilon = 0.15$, this peak response occurs approximately four periods after the shock. Although the accumulation of organizational capital might be associated with a hump-shaped response in output, an examination of Figures 3.4 and 3.5 reveals that the peak response in output is lower for larger values of ε.

An examination of Appendix A.3 reveals ε appears in the linearized system both by itself and as the product $\varepsilon\gamma$. This suggests that the effect of alternative values of ε upon the dynamic responses will depend upon the particular value of γ. As stated above, larger values of ε will be associated with a lower effective depreciation rate of organizational capital. However, the magnitude of this effect depends upon the particular value of γ. For this reason it is useful to explore the impact of alternative values of ε, for several values of γ.[13]

For a given value of ε, the impact of a larger value of γ is somewhat complicated. This is because the assumption of a constant returns to scale accumulation technology necessarily requires that larger values of γ are equivalent to lower values of η. Therefore, for a given percentage deviation in the stock of organizational capital,

[13]The dynamic responses, for the organizational capital model with a log-linear technology, for alternative values of ε and γ, are presented in Figures 3.6 to 3.14.

larger values of γ raise the contribution of the percentage deviation in labour and physical capital to future percentage deviations in organizational capital. However, larger values of γ also alter the effective depreciation rate of organizational capital. For a given percentage deviation in physical capital and labour, larger values of γ will alter the coefficient associated with the contribution of the existing stock of organizational capital to the future stock of organizational capital. In particular, increases in the value of γ will alter this coefficient by a factor $(\varepsilon - 1) < 0$. This suggests that larger values of γ will *increase* the effective depreciation rate of organizational capital with the size of the increase determined by the value of ε. Consequently, it is expected that the impact of alternative values of ε upon the dynamic responses, for a relatively low value of γ might be different than the effects associated with a larger value of γ.

Recall that the values for both ε and γ considered in this chapter are based upon the estimates provided by Cooper & Johri (2002) and Johri & Letendre (2002). Generally, these structural parameters are estimated with considerable imprecision Given this, it is important to consider how alternative values of γ and ε might affect the implied dynamic responses.

As has been discussed above, for a value of $\gamma = 0.2$, the dynamic response of investment in the organizational capital model will characterized by a hump-shaped pattern that does not appear in a model that ignores organizational capital. In addition, for a sufficiently large value of ε output will be characterized by a hump-shaped response. Since these hump-shaped responses are an important feature of the empirical responses, and consequently represent a shortcoming of the model that ignores organizational capital, it is worthwhile considering how the interaction of alternative values of both ε and γ affect the dynamic responses. It is clear from the above discussion that alternative values of both γ and ε might be expected to affect the dynamic responses in several ways

As identified above, for a given value of $\gamma = 0.2$, larger values of ε will be associated with a larger peak response in organizational capital and a delay in the emergence of this peak response. Unfortunately, this result does not hold for all values of γ. For example, when $\gamma = 0.05$, larger values of ε will be associated with a (slightly) reduced peak response in organizational capital while for $\gamma = 0.35$, larger values of ε will be associated with a larger peak response. In comparison, for a given value of ε, larger values of γ will be associated with a larger peak response in organizational capital which occurs relatively earlier in the transition path for larger values of γ. These results suggest that the interaction of ε with γ is quite important for the dynamic response of organizational capital and consequently the dynamic response in output. As noted above, this differing response in organizational capital will also affect the dynamic responses for consumption, investment, employment and physical capital.

Importantly, for a relatively low value of γ, a value of $\varepsilon = 0.15$ will not be sufficient to generate a hump-shaped response in output. Similarly, a relatively large value of $\gamma = 0.35$ and a low value of $\varepsilon = 0.05$ will not be sufficient to generate a hump-shaped response in output. Therefore, this hump-shaped response in output requires both a sufficiently large value of γ and ε. Indeed, the hump-shaped response in output becomes more pronounced for larger values of γ and ε. Intuitively, both ε and γ affect the importance of the dynamic structure associated with the accumulation of organizational capital. However, these parameters affect this dynamic structure in several ways so that it is the interaction of these structural parameters that matters for the dynamic responses.

Consistent with this hump-shaped response in output, a sufficiently large value of γ together with a sufficiently large value of ε might generate a small hump-shaped response in employment. Fundamentally, it is the additional impact of a larger value of γ upon the implied dynamic structure that produces this hump-shaped response in employment.

The interaction of a sufficiently low value of ε with a sufficiently low value of γ implies that investment need not exhibit a hump-shaped pattern. Indeed for $\varepsilon = 0.05$ and $\gamma = 0.05$, investment will decline monotonically to its steady state level. This is primarily because the interaction of relatively low values for both ε and γ implies that the dynamic structure associated with the accumulation of organizational capital will be relatively unimportant. However, provided the value of γ is sufficiently large, investment will be characterized by a hump-shaped pattern even for a low value of ε. Once again this hump-shaped response in investment becomes more pronounced for larger values of both γ and ε.

The dynamic responses presented in Figures 3.1 to 3.3 strengthen the implications arising from the accumulation of organizational capital and identified for a purely transitory shock. Compared to a model that ignores organizational capital, the accumulation of organizational capital is able to generate persistent increases in output above its steady state level. For a sufficiently large value of ε and γ, this output response will exhibit a hump-shaped response which is, at least qualitatively, consistent with the empirical response identified by Edelberg et al. (1999). In addition, along the transition path to the steady state, investment will be characterized by a hump-shaped response. This hump-shaped response in investment is consistent with the empirical response identified in Edelberg et al. (1999) and does not appear in the model that ignores organizational capital. This suggests that the general equilibrium effects of allowing for the accumulation of organizational capital by production units will likely be an important component of the endogenous propagation mechanism identified by Cooper & Johri (2002).

In addition, the aggregate effects of allowing for the accumulation of organizational capital depend critically upon the magnitude of the parameters ε and γ. Importantly, the ability of the organizational capital model to generate dynamic responses that are qualitatively similar to the empirical responses requires sufficiently large values for these parameters which essentially reflect the importance of the dynamic structure associated with the accumulation of organizational capital.

Given this importance of the magnitude of the accumulation technology γ, and its interaction with ε, it is natural to consider whether the dynamic responses associated with the accumulation of organizational capital depend critically upon the functional form assumed for the accumulation technology.

3.5 The Accumulation Technology—Linear or Log-Linear?

The previous section has established that a structural model in which the accumulation of organizational capital is characterized by a log-linear accumulation technology may produce quite different dynamic responses along the transition path to the steady state, compared to an otherwise equivalent model that ignores this accumulation of organizational capital.

The previous chapter detailed a calibration strategy in which the ratios of key variables in the non-stochastic steady state will be independent of the values of the organizational capital parameters. It was also shown that the non-stochastic steady state implied by the log-linear accumulation technology will be approximately equivalent to the non-stochastic steady state implied by the linear technology. Indeed, when there is no growth in the level of technology so that $\psi_x = 0$, these non-stochastic steady states will be identical.

This result arises because the existence of a feasible steady state imposes a particular relationship between the growth rate in organizational capital and the growth rate in output. When the accumulation technology exhibits constant returns to scale, the growth rate in organizational capital must be identical to the growth rate in output, in a feasible steady state. Note that the linear accumulation technology will exhibit (global) constant returns to scale and the log-linear technology is assumed to exhibit constant returns to scale. Consequently, the requirement that the growth rate in output be equal to the growth in organizational capital imposes an additional constraint on the feasible steady states.

This constant returns to scale assumption simply requires that the growth rate in output equals the growth rate in organizational capital. It does not require that the growth rate in output (or organizational capital) in the model with a log-linear technology equal the growth rate in output (or organizational capital) in the model with a linear technology. However, as shown in the previous chapter, when the accumulation technology exhibits constant returns to scale, the growth rate in output will not depend upon the organizational capital parameters and in particular it will not depend upon the function form of the accumulation technology. Therefore, the (steady state) growth rate in organizational capital in the model with a log-linear technology must be identical to the steady state growth rate in organizational capital for the model with a linear technology. This considerably restricts the feasible steady states that might emerge in the model characterized by a log-linear technology, compared to the model characterized by a linear technology.

An examination of the first order conditions from the plant's maximization problem (in the transformed economy), presented in the previous chapter, reveals that the functional form for the accumulation technology alters the form of these first order conditions. Note that this difference in the first order conditions essentially arises because the rate of depreciation in organizational capital implied by the log-linear technology is quite different than that implied by the linear technology. The log-linear technology implies that a constant percentage of the stock of organizational capital is lost each period whereas the linear technology implies that the per-period loss is a constant amount of the stock of organizational capital. Consequently, any difference in the non-stochastic states associated with these alternative accumulation technologies reflects this difference in the first order conditions, consistent with the feasible steady states. Essentially, this is reflected in a slightly different expression for the plant multiplier λ_f in the non-stochastic steady state for the linear technology, compared to the log-linear technology.

Although the magnitudes of key variables, such as the k/y and z/y ratio, in the non-stochastic state of the model with a log-linear technology might be approximately equal to those associated with a linear technology, it need not be true that this equivalence would be preserved outside the non-stochastic steady state. This can be seen by examining the linearized first order conditions in the neighbourhood of the non-stochastic steady state and presented in Appendix A.3.

With the exception of a small growth effect, the coefficients in the linearized form of these accumulation technologies will be (approximately) equal when the organizational capital parameters are identical ($\gamma = 1 - \phi_1$).[14] Of course this equivalence follows directly from the function form assumptions so that the log-linear technology is linear in percentage deviations from the steady state.

Differences in the dynamic responses for the linear and the log-linear accumulation technologies might arise because the transition path for the plant multiplier will be different. In turn this different behaviour of the plant multiplier outside the steady state reflects the implied curvature in the accumulation technology. Recall, from the previous chapter, the log-linear technology will be given by:

$$z_{t+1} - \exp\left[-\chi(\eta + \varepsilon\gamma + \theta\gamma)(\psi_x + \zeta_t)\right] z_t^{\eta+\varepsilon\gamma} k_t^{\theta\gamma} H_t^{\alpha\gamma} = 0$$

[14]This restriction is imposed in order to facilitate a comparison of the dynamic responses for the linear technology to those for the log–linear technology. However, a comparison of the estimates in Cooper & Johri (2002) to the estimates provided by Benkard (2000) suggest that this restriction might be appropriate as an approximation.

The marginal productivity of z_{t+1}, holding capital and labour fixed, will be decreasing in the stock of organizational capital. Similarly the linear technology will be given by:

$$z_{t+1} - \phi_1 \, z_t \, \exp\left[-\chi(\psi_x + \zeta_t)\right] - \phi_2 \, H_t^{\alpha} \, k_t^{\theta} \, z_t^{\varepsilon} \, \exp\left[-\chi(\theta + \varepsilon)(\psi_x + \zeta_t)\right] = 0$$

For this linear technology, the marginal productivity of z_{t+1}, holding capital and labour fixed, will also be decreasing in the stock of organizational capital. Note that this diminishing marginal productivity in the linear accumulation technology arises only from the diminishing marginal productivity of organizational capital in the production technology. In contrast, the diminishing marginal productivity in the log-linear technology arises from both the degree of curvature in the production technology *and* the accumulation technology. The implications of this differing degree of diminishing marginal productivity in the accumulation technology is reflected in the linearized equation for the plant multiplier. In particular, the linearized equation for the linear technology (with no technology shocks) will be given by:

$$\psi_5 \, \hat{H}_{t+1} - \psi_5, \hat{z}_{t+1} - \psi_5 \, \hat{\lambda}_{t+1}^{h} + (1 - \psi_5) \, \hat{\lambda}_{t+1}^{f} = 0 \tag{3}$$

The linearized equation for the log-linear technology will be given by:

$$\begin{aligned} &\psi_5 \, \hat{H}_{t+1} - \psi_5, \hat{z}_{t+1} - \psi_5 \, \hat{\lambda}_{t+1}^{h} + (1 - \psi_5) \, \hat{\lambda}_{t+1}^{f} \\ &\qquad + (1 - \psi_5) \, \alpha\gamma \, \hat{H}_{t+1} + (1 - \psi_5) \, \theta\gamma \, \hat{k}_{t+1} - (1 - \psi_5)(\eta + \varepsilon\gamma) - 1) \, \hat{z}_{t+1} = 0 \end{aligned}$$

Note that the magnitude of the coefficients ψ_{41}, ψ_{42}, and ψ_5 in the model characterized by a log-linear technology will, in general, differ from those associated with a linear technology. However, the calibrated (quarterly) growth rate in output is sufficiently small so these coefficients will be approximately equal under the alternative accumulation technologies.

It is clear that, for the log-linear technology, there are extra terms in the linearized first order condition that controls the transition path for the plant level shadow price $\hat{\lambda}_t^f$. These extra terms appear because, in the case of a log-linear accumulation technology, the first order conditions that determine the optimal labour demand and the optimal stock of organizational capital depend upon the current stock of organizational capital and the expected stock of organizational capital next period. In contrast, the first order conditions associated with a linear technology do not depend upon this stock of organizational capital. Therefore, the assumption of a log-linear technology has the potential to considerably alter the plant level dynamics such that the dynamic response to a fiscal shock might be quite different than that for the linear technology.

Figures 3.6 to 3.14 compare the dynamic responses for the model characterized by a log-linear technology to those for the model characterized by a linear technology, for the same value of ε and $\gamma = \phi_2$. Prior to comparing the dynamic responses for the linear technology to the log-linear technology it is worthwhile to examine how alternative values of ϕ_2 and ε affect the dynamic responses for the linear technology. Generally, despite some slight differences, alternative values of ϕ_2 and ε affect the dynamic responses in much the same way as alternative values of γ and ε affect the dynamic responses associated with a log-linear technology.

This is most easily seen by considering the total response to the fiscal shock as summarized in Table 3.3. Essentially, this a crude way of integrating the dynamic responses over the transition path to the steady state. Since all of the aggregate variables of interest have more or less returned to their steady state values after say 100 periods, the results presented in Table 3.3 sum the dynamic responses over the first 100 periods following the persistent yet temporary fiscal shock. As with the log-linear technology, for a given value of ε, larger values of ϕ_2 will be associated with a larger total response in output, investment, physical capital, employment, and organizational capital with a lower (negative) response in consumption. These results will also hold for larger values of values of ε, for a given value of ϕ_2.

Figures 3.6 to 3.14 reveal that, for a given value of ε and $\gamma = \phi_2$, the dynamic responses associated with a log-linear technology will be qualitatively similar to those associated with a linear technology. Despite this, it is possible to identify some important differences in the dynamic responses associated with the linear technology, relative to those for the log-linear technology. In order to understand these differences it is worthwhile comparing the total responses for the log-linear technology compared to the linear technology.

It is clear from Table 3.3 that, for a given value of ε, and $\phi_2 = \gamma$, the magnitude of the total responses for the linear technology always exceeds that associated with the log-linear technology. This most likely reflects the additional source of diminishing marginal productivity of organizational capital in the model characterized by a log-linear technology associated with the curvature in the accumulation technology. For a given value of ε, the magnitude of the total responses for the log-linear model become closer to those associated with the linear technology, for larger values of $\gamma = \phi_2$. Although the effects of alternative values of $\gamma = \phi_2$ are quite complicated for both models, the intuition for this result is that the difference in the transition path for the plant multiplier associated with the log-linear technology, compared to the linear technology, becomes less important for larger values of $\gamma = \phi_2$. In contrast, for a given value of $\gamma = \phi_2$, larger values of ε will be associated with a larger difference in the magnitude of the total responses for the log-linear technology compared to those for the linear technology.

An examination of Table 3.3 also reveals that, compared to the log-linear technology, changes in the value of ϕ_2, for a given value of ε, have a smaller impact upon the total responses for the linear technology, for larger values of ϕ_2. In contrast, for a given value of $\gamma = \phi_2$, larger values of ε produce a much larger impact upon the total responses for the linear technology, compared to the log-linear technology. Once again these results might be interpreted in terms of the differing impact of these organizational capital parameters upon the degree of diminishing marginal productivity of organizational capital and the optimal response in the plant level multiplier.

These differences in the total responses for the model characterized by a log-linear technology, compared to those for the linear technology, will be reflected in the dynamic responses presented in Figures 3.6 to 3.14. These differences are primarily driven by differences in the dynamic response of the plant multiplier λ_t^f which affects the optimal percentage deviation in organizational capital and output. For example, the total response in output associated with a linear technology, always exceeds that associated with the log-linear technology for given values of ε and $\gamma = \phi_2$. In the presence of consumption smoothing, the dynamic response of consumption associated with the linear technology should always be less negative than that associated with the log-linear technology.

As noted in the previous section, the transition path for the plant level multiplier λ_t^f governs the optimal allocation of organizational capital along the transition path which affects both the allocation of output across periods and the optimal input combinations of employment and physical capital. For a given value of ε and $\gamma = \phi_2$, along the transition path, the linear technology will be characterized by a slightly larger response in employment and physical capital, compared to the log-linear technology. In conjunction with the optimal consumption response, these differing dynamic responses in employment and physical capital affect the optimal response of investment along the transition path. Specifically, in the presence of consumption smoothing and a larger impact employment response, the model characterized by a linear technology will involve a relatively larger optimal impact response in investment. An examination of Figures 3.6 to 3.14 reveals that this is the most striking distinguishing feature of the dynamic response for the model with a linear accumulation technology.

An important distinguishing feature of the model that allows for the accumulation of organizational capital is that investment might be characterized by a hump-shaped dynamic response that does not appear in a model that ignores organizational capital. As with the log-linear technology, for a sufficiently large value of $\gamma = \phi_2$ and ε, the model with a linear accumulation technology will also be characterized by a hump-shaped response in investment. However, in contrast to the log-linear technology, low values of ϕ_2 will never be associated with a hump-shaped response in investment, even for relatively large values of ε. Intuitively, for the model with a linear technology, the optimal increase in investment in the impact period and the resulting transition path in investment is sufficient to deliver the desired stock of physical capital along the transition path to the steady state. For larger values of ϕ_2, the optimal jump in investment is not sufficient to deliver the desired physical capital stock and consequently, the transition path will require increases in investment in subsequent periods.

Similar to the log-linear technology, the accumulation of organizational capital characterized by a linear technology, will produce a hump-shaped response in output (for sufficiently large values of ε and $\gamma = \phi_2$). Indeed, the response of output in the model with a linear technology is extremely similar, at least qualitatively, to the response of output in the model with a log-linear technology. Despite this, for the values of $\gamma = \phi_2$ and ε considered, the linear technology will never be associated with a hump-shaped response in employment. Recall that for a sufficiently large value of γ and ε, the model with a log-linear technology might be consistent with a (slight) hump-shaped response in employment. This result probably arises from two sources. Firstly, the linear technology implies slightly different (optimal) input combinations of employment and physical capital along the transition path. Secondly, the slightly less (negative) consumption response associated with the linear technology implies a less (negative) real wage response, compared to the log-linear technology. These two factors together suggest that it may never be optimal to increase employment beyond the impact period.

It is clear from both Table 3.3 and Figures 3.6 to 3.14 that the dynamic responses of the model characterized by a log-linear technology might be quite similar to those associated with a linear technology. Of course, an evaluation of whether these dynamic responses are quantitatively similar would require estimation of the full structural model. The results presented above suggest that both of these functional forms might be associated with both a hump-shaped response in investment and a hump-shaped response in output. As noted above, a model that ignores the accumulation of organizational capital is unable to generate these hump-shaped responses which are an important feature of the empirical responses. This suggests that the endogenous propagation mechanism associated with the accumulation of organizational capital, and identified by Cooper & Johri (2002), probably does not critically depend upon the particular functional form assumed for the accumulation technology. Importantly, it is the accumulation of organizational capital and the resulting dynamic structure that it implies for the plant's maximization problem that generates this endogenous propagation mechanism rather than any specific functional form assumptions.

Both the log-linear and the linear forms of the accumulation technology have been chosen because they feature prominently in existing studies of learning-by-doing. The limited literature that explores the impact of allowing for the accumulation of organizational capital upon macroeconomic fluctuations has restricted attention to the log-linear accumulation technology. However, the microeconomic literature studying learning-by-doing has largely restricted attention to the linear accumulation technology. For example, Benkard (2000) uses a linear accumulation technology with the restriction $0 < \phi_1 < 1$ and $\phi_2 = 1$. Therefore, a comparison of the dynamic responses for the linear accumulation technology, compared to the those for the log-linear technology allows an integrated study of these two approaches to the (structural) modelling of learning-by-doing. The results presented above suggest that the macroeconomic differences might be quite similar, particularly for specific values of ε and $\gamma = \phi_2$.

The advantage of the log-linear accumulation technology is that the first order conditions arising from the plant's maximization problem do not depend upon the stock of organizational capital. This implies that the structural parameters η and γ may be estimated without requiring data on the entire history of the plant since birth. The first order conditions associated with a log-linear accumulation technology imply the following:

$$\frac{\alpha}{\mu}\frac{y_t}{w_t H_t} + \beta E_t\left[\exp\left[\chi(\psi_x + \zeta_{t+1})\right]\left\{(\eta + \varepsilon\gamma)\frac{w_{t+1}H_{t+1}}{w_t H_t} - \eta\frac{\alpha}{\mu}\frac{y_{t+1}}{w_t H_t}\right\}\right] - 1 = 0$$

Alternatively, the first order conditions associated with the linear accumulation technology imply the following:

$$\frac{\alpha}{\mu}\frac{y_t}{w_t H_t} + \beta E_t\left[\frac{w_{t+1}H_{t+1}}{w_t H_t}\left\{\exp\left[\chi(\psi_x + \zeta_{t+1})\right]\varepsilon\phi_2\frac{y_t}{z_{t+1}} + \phi_1\frac{y_t}{y_{t+1}}\right\}\right] - 1 = 0$$

It is clear that, even when there is no growth in the level of technology, the structural parameters ϕ_1 and ϕ_2 cannot be estimated without knowledge of the stock of organizational capital.

3.6 Conclusions

This chapter has examined the transitional dynamics, associated with a temporary, unanticipated exogenous increase in government consumption, for a structural model in which production units accumulate production experience. It has been shown that, relative to a model that ignores the accumulation of organizational capital, this structural model is able to generate a hump-shaped dynamic response for output, for particular values of the organizational capital parameters. This suggests that the accumulation of production experience by production units will likely be an important component of the endogenous propagation mechanism identified by Cooper & Johri (2002). Consequently, a key component of this endogenous propagation mechanism, the joint hypothesis of monopolistic competition and organizational capital accumulation, implies producers face a trade-off between maximizing current period profits and losing future productivity increases.

This structural model is also able to generate a hump-shaped response in investment. A hump-shaped response in investment and output is an important feature of the empirical dynamic responses associated with the onset of a typical Ramey-Shapiro episode. More importantly, a model that ignores organizational capital is unable to produce dynamic responses in output and investment that exhibit this hump-shaped response. Consequently, at least qualitatively, the dynamic responses associated with the accumulation of organizational capital might be consistent with the stylized facts associated with the empirical responses. Future research will need to investigate whether these dynamic responses are *quantitatively* consistent with the empirical responses, including an examination of how distortionary taxation might affect the dynamic responses.

This chapter has also investigated the dynamic responses for a linear accumulation technology, compared to those for a log-linear accumulation technology. The result suggest that the endogenous propagation mechanism associated with the accumulation of organizational capital, and identified by Cooper & Johri (2002), probably does not critically depend upon the particular functional form assumed for the accumulation technology. Importantly, it is the accumulation of organizational capital and the resulting dynamic structure that it implies for the plant's maximization problem that generates this endogenous propagation mechanism rather than any specific functional form assumptions. This comparison between the aggregate implications associated with a linear or a log-linear accumulation technology provides a bridge between the largely macroeconomic literature that has used a log-linear technology and the largely microeconomic literature that has used a linear technology.

This chapter has shown that these dynamic responses might depend critically upon the values of the organizational capital parameters. This suggests that it will be extremely important to obtain reliable estimates of these parameters, in order to fully evaluate the aggregate implications of allowing for the accumulation of organizational capital and provide reliable policy conclusions. Using the log-linear accumulation technology, the next chapter provides some estimates of these organizational capital parameters based upon a lengthy panel of continuing Canadian manufacturing establishments.

	No Organizational Capital			**Organizational Capital**		
	$\gamma = \mathbf{0.20}$ $\eta = \mathbf{0.80}$					
ε	0.0500	0.1000	0.1500	0.0500	0.1000	0.1500
β[a]	0.9926	0.9926	0.9926	0.9926	0.9926	0.9926
ψ_x	0.0040	0.0040	0.0040	0.0037	0.0034	0.0031
χ	1.0000	1.0000	1.0000	1.0856	1.1873	1.3100
μ	1.1071	1.1674	1.2348	1.1071	1.1674	1.2348
δ	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
θ	0.3661	0.3661	0.3661	0.3661	0.3661	0.3661
α	0.6339	0.6339	0.6339	0.6339	0.6339	0.6339
rts	1.0000	1.0000	1.0000	1.0526	1.1111	1.1765
$\alpha + \theta$	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
θ/α	0.5775	0.5775	0.5775	0.5775	0.5775	0.5775
Φ	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034
z/y				0.9841	0.9841	0.9841
k/y	10.0979	9.5757	9.0536	10.6200	10.6200	10.6200
c/y	0.5672	0.5805	0.5937	0.5540	0.5540	0.5540
i/y	0.2558	0.2425	0.2293	0.2690	0.2690	0.2690
g/y	0.1770	0.1770	0.1770	0.1770	0.1770	0.1770
lsh	0.5726	0.5430	0.5134	0.6022	0.6022	0.6022
ksh	0.3320	0.3148	0.2977	0.3492	0.3492	0.3492
ksh^*[b]	0.3307	0.3136	0.2965	0.3478	0.3478	0.3478
$lsh + ksh^*$	0.9033	0.8566	0.8099	0.9500	0.9500	0.9500
$markup$	1.1071	1.1674	1.2348	1.0526	1.0526	1.0526

[a] β denotes the discount rate, δ denotes the depreciation rate of physical capital, Φ denotes a preference parameter, α, is a Cobb-Douglas production technology parameter associated with labour, θ, is a Cobb-Douglas production technology parameter associated with physical capital, ε is a Cobb-Douglas production technology parameter associated with organizational capital, γ and η are the parameters of the log-linear accumulation technology, μ is a demand parameter, ψ_x denotes the growth rate in the level of technology, and $\chi = \alpha/(1 - \theta - \varepsilon)$. The term lsh represents the share of labour in total revenues and ksh refers to the share of physical capital in total revenues.
[b] $ksh^* = ksh \exp(-\chi\psi_x)$

Table 3.1: Calibrated Structural Parameters

	Percentage Deviation from Steady State							
	Period							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	No Organizational Capital							
c, w	-0.0094	-0.0089	-0.0084	-0.0080	-0.0075	-0.0071	-0.0068	-0.0064
y[a]	0.0163	-0.0008	-0.0008	-0.0007	-0.0007	-0.0007	-0.0006	-0.0006
i	-0.6402	0.0179	0.0169	0.0160	0.0152	0.0144	0.0136	0.0129
k	0	-0.0162	-0.0154	-0.0145	-0.0138	-0.0130	-0.0123	-0.0117
h	0.0256	0.0081	0.0076	0.0072	0.0068	0.0065	0.0061	0.0058
z								
g	1	0	0	0	0	0	0	0
	Organizational Capital							
c, w	-0.0089	-0.0084	-0.0079	-0.0075	-0.0071	-0.0067	-0.0063	-0.0060
y	0.0132	0.0003	0.0002	0.0001	0.0001	0.0000	0.0000	0.0000
i	-0.5906	0.0184	0.0171	0.0160	0.0150	0.0140	0.0131	0.0123
k	0	-0.0150	-0.0141	-0.0133	-0.0126	-0.0119	-0.0112	-0.0106
h	0.0208	0.0087	0.0081	0.0076	0.0072	0.0067	0.0064	0.0060
z	0	0.0026	0.0022	0.0018	0.0015	0.0012	0.0010	0.0008
g	1	0	0	0	0	0	0	0

[a] In percentage deviations from the non-stochastic state c represents aggregate consumption, w denotes the real wage, y denotes aggregate output, i denotes aggregate investment in physical capital, k denotes the stock of physical capital, h denotes employment, z denotes the stock of organizational capital and g represents government consumption.

Table 3.2: Transient Government Shock: $\varepsilon = 0.10$ and $\gamma = 0.2$

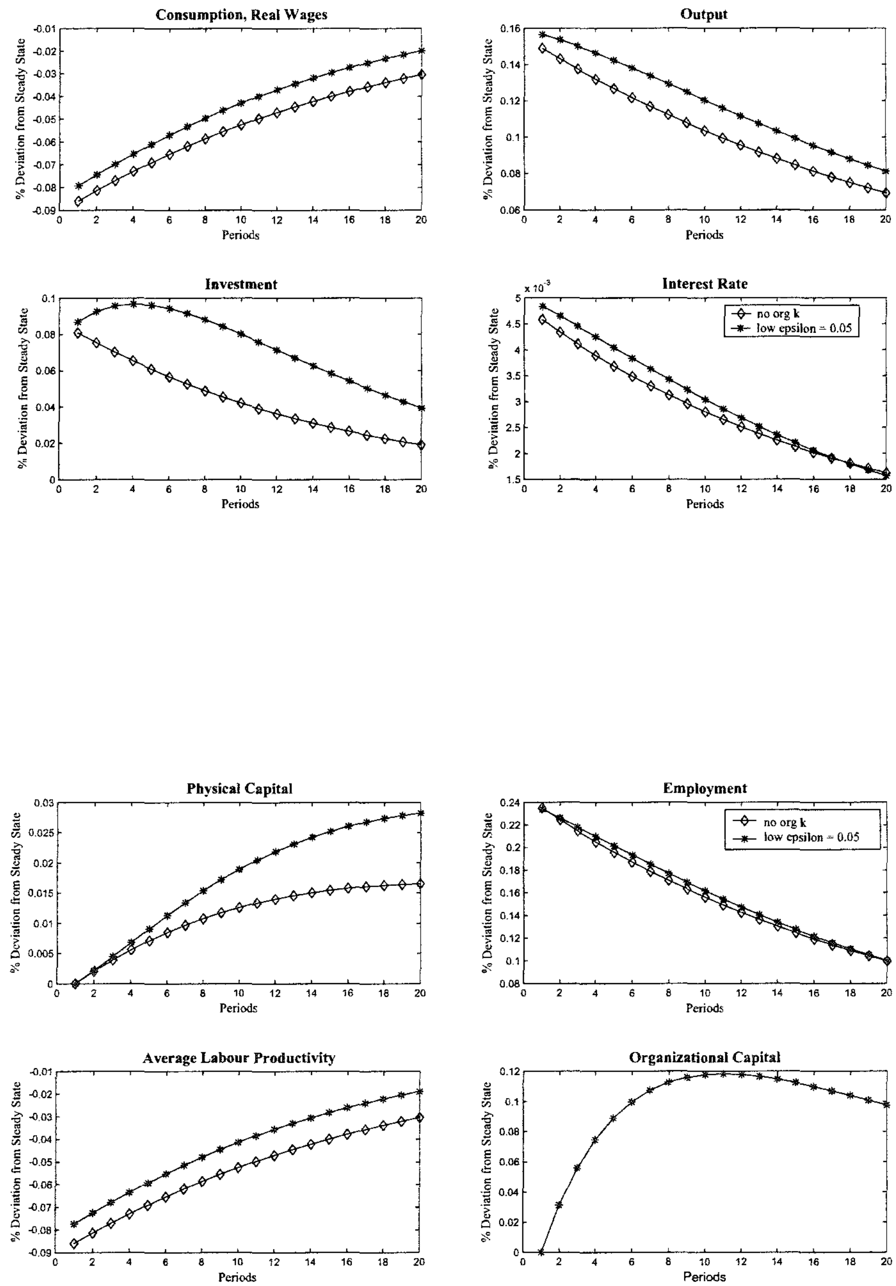

Figure 3.1: The Effect of Organizational Capital: $\eta = 1 - \gamma = 0.8$, $\varepsilon = 0.05$

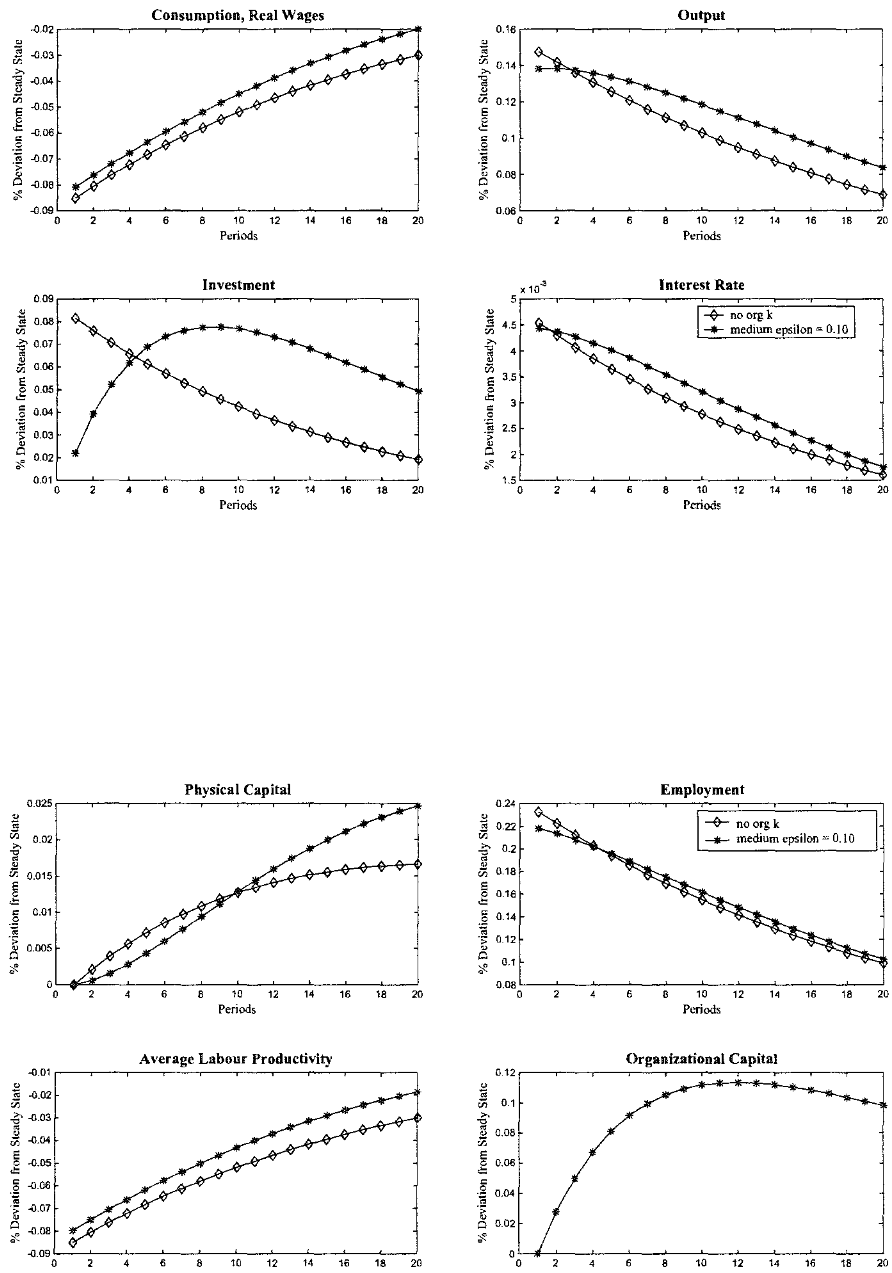

Figure 3.2: The Effect of Organizational Capital: $\eta = 1 - \gamma = 0.80$, $\varepsilon = 0.10$

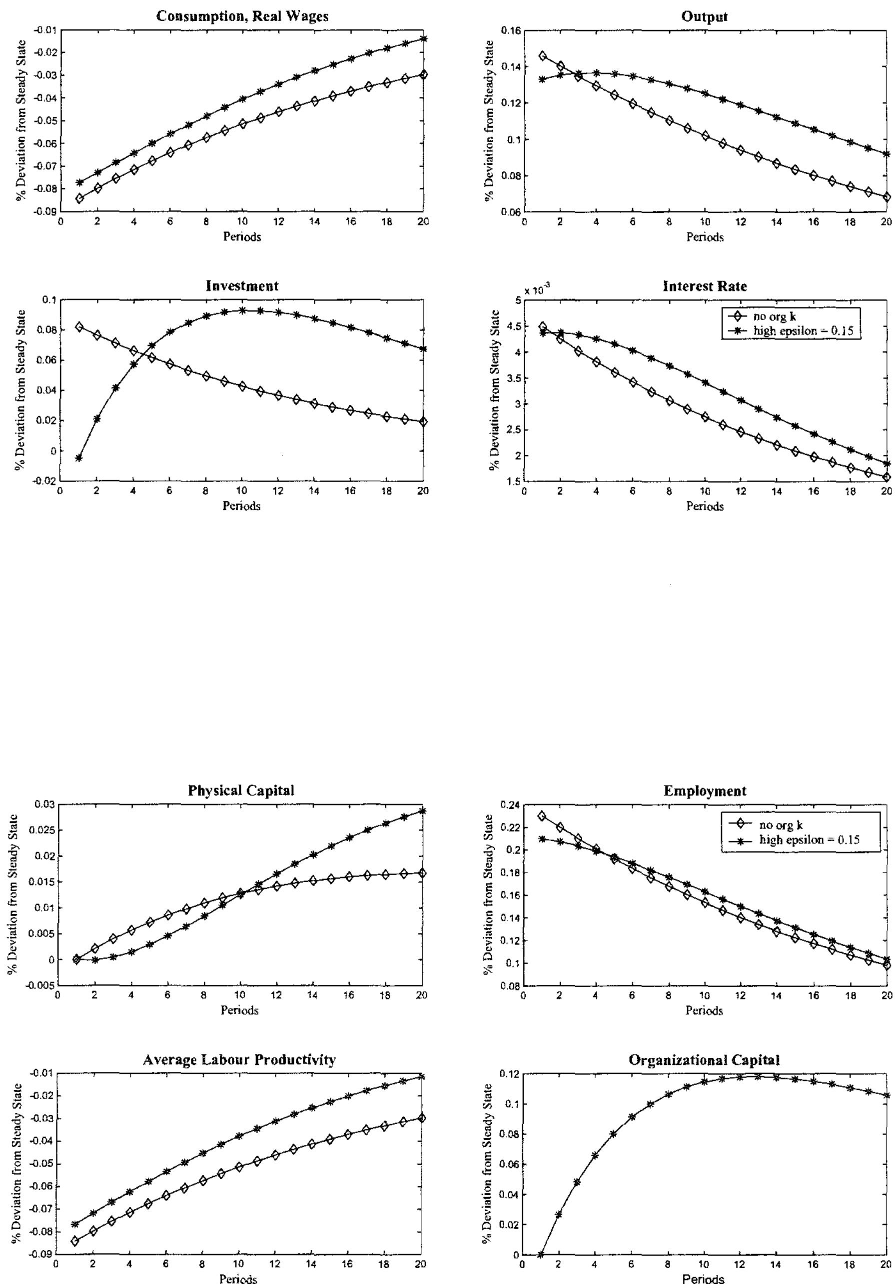

Figure 3.3: The Effect of Organizational Capital: $\eta = 1 - \gamma = 0.80$, $\varepsilon = 0.15$

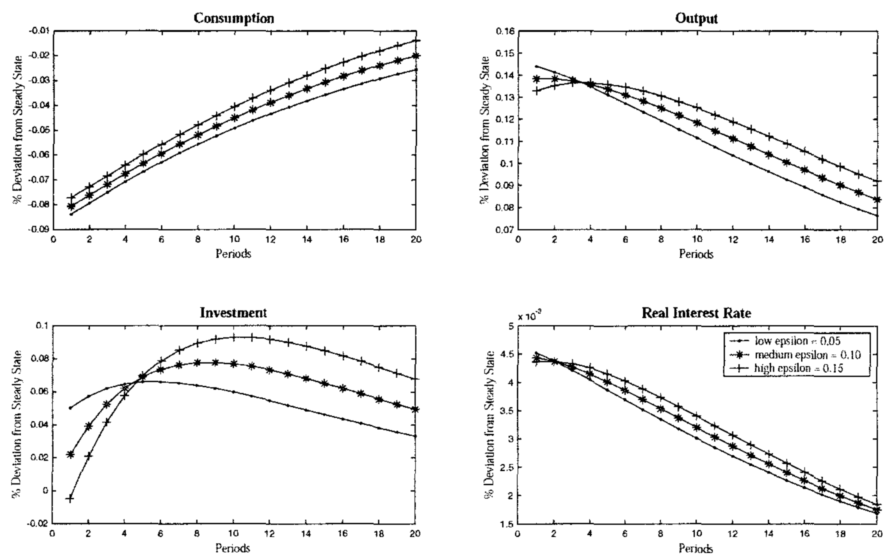

Figure 3.4: Log–Linear : Alternative ε with $\eta = 1-\gamma = 0.80$—Consumption, Output, Investment, Real Interest Rate

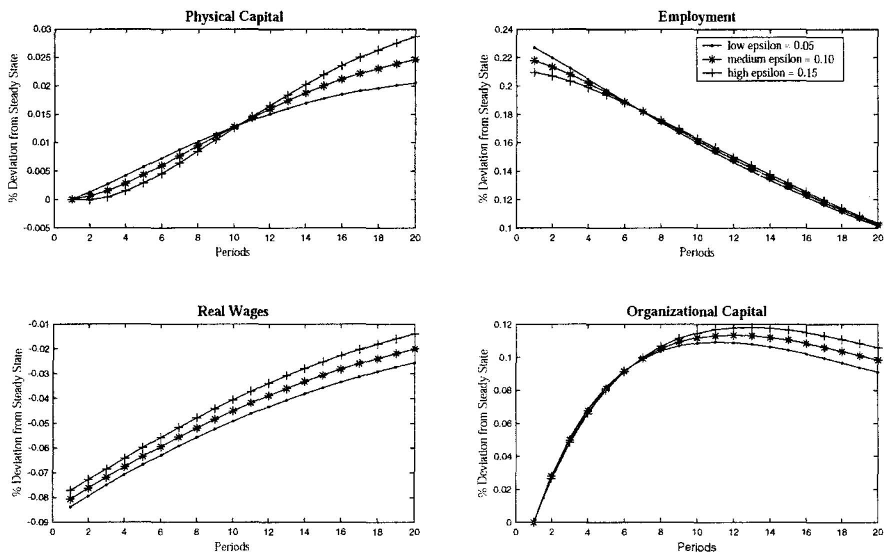

Figure 3.5: Log–Linear : Alternative ε with $\eta = 1 - \gamma = 0.80$——Physical Capital, Employment, Real Wages, Organizational Capital

	loglin	lin	loglin	lin	loglin	lin
	$\varepsilon = \mathbf{0.05}$					
γ	0.0500		0.2000		0.3500	
ϕ_2		0.0500		0.2000		0.3500
k	0.9685	1.0974	1.2054	1.2489	1.2658	1.2896
z	3.6530	3.7585	3.9572	3.9835	3.9910	4.0135
c	-1.4500	-1.3710	-1.3197	-1.2935	-1.2885	-1.2743
h	5.2175	5.2517	5.2623	5.2760	5.2765	5.2842
y	3.8447	3.9188	3.9750	4.0010	4.0083	4.0225
alp[a]	-1.3728	-1.3328	-1.2872	-1.2750	-1.2682	-1.2616
i	1.1066	1.2194	1.3226	1.3650	1.3821	1.4057
	$\varepsilon = \mathbf{0.10}$					
γ	0.0500		0.2000		0.3500	
ϕ_2		0.0500		0.2000		0.3500
k	1.0312	1.3008	1.5443	1.6407	1.6837	1.7370
z	3.7607	3.9579	4.2516	4.3101	4.3396	4.3720
c	-1.2671	-1.0967	-0.9724	-0.9134	-0.8979	-0.8655
h	5.0915	5.1541	5.1758	5.2024	5.2049	5.2198
y	3.9812	4.1393	4.2716	4.3295	4.3498	4.3820
alp	-1.1103	-1.0148	-0.9042	-0.8728	-0.8551	-0.8378
i	1.2373	1.4739	1.7099	1.8038	1.8473	1.9002
	$\varepsilon = \mathbf{0.15}$					
γ	0.0500		0.2000		0.3500	
ϕ_2		0.0500		0.2000		0.3500
k	1.0887	1.5115	1.9290	2.0857	2.1670	2.2581
z	3.8702	4.1706	4.5877	4.6866	4.7384	4.7939
c	-1.0756	-0.7994	-0.5739	-0.4731	-0.4386	-0.3825
h	4.9590	5.0435	5.0761	5.1141	5.1201	5.1418
y	4.1227	4.3761	4.6104	4.7084	4.7498	4.8052
alp	-0.8363	-0.6674	-0.4657	-0.4056	-0.3703	-0.3365
i	1.3688	1.7421	2.1485	2.3055	2.3884	2.4787

[a] See the notes attached to Tables 3.1 and 3.2. The term *alp* refers to average labour productivity.

Table 3.3: Cumulative Dynamic Responses: Persistent Fiscal Shock

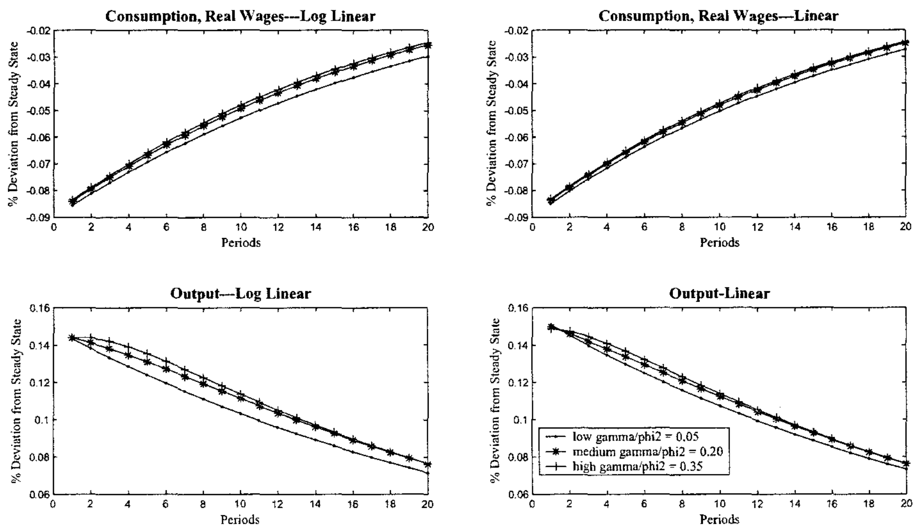

Figure 3.6: Log–Linear & Linear: Alternative $\gamma = \phi_2$ with $\varepsilon = 0.05$—Consumption and Output

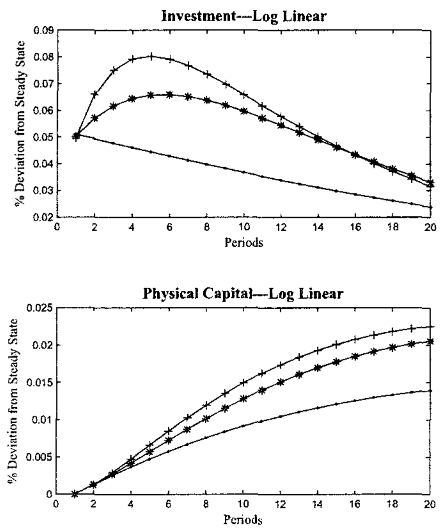

Figure 3.7: Log–Linear & Linear: Alternative $\gamma = \phi_2$ with $\varepsilon = 0.05$—Investment and Physical Capital

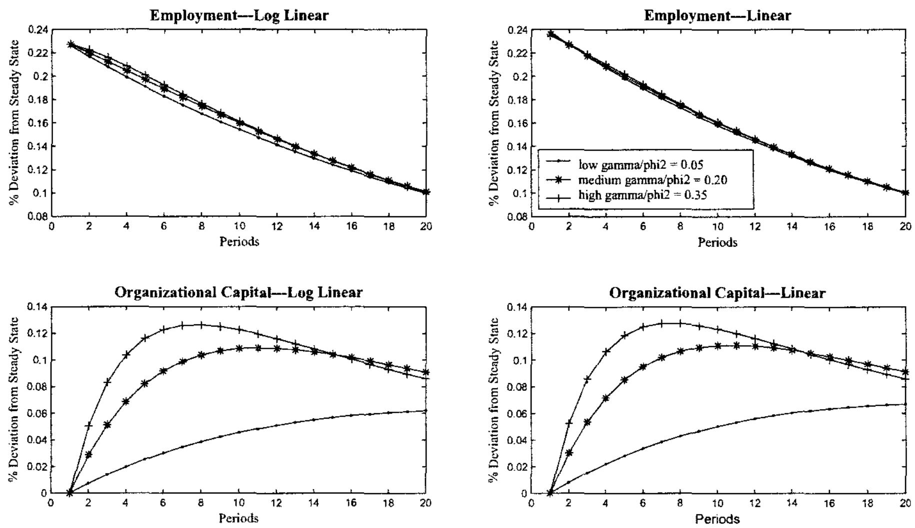

Figure 3.8: Log–Linear & Linear: Alternative $\gamma = \phi_2$ with $\varepsilon = 0.05$—Employment and Organizational Capital

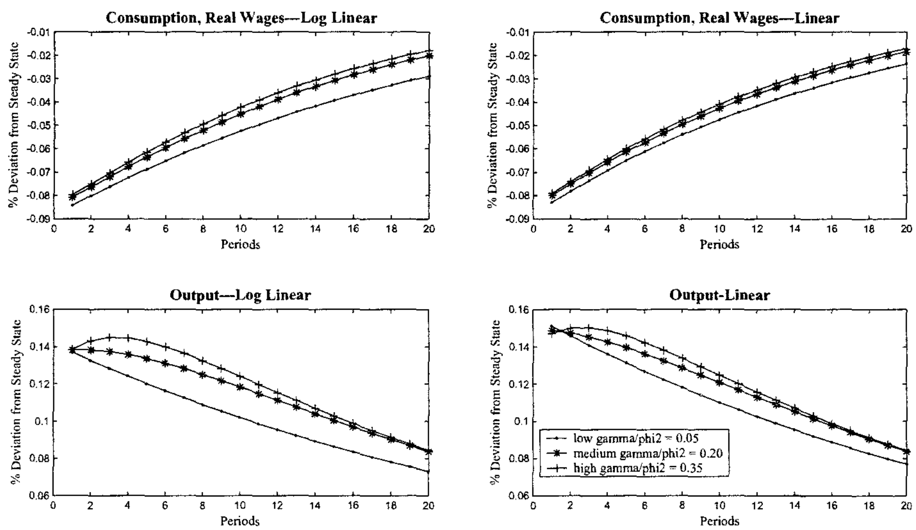

Figure 3.9: Log–Linear & Linear: Alternative $\gamma = \phi_2$ with $\varepsilon = 0.10$—Consumption and Output

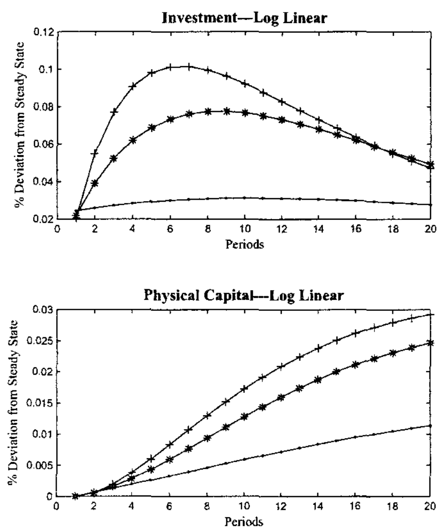

Figure 3.10: Log–Linear & Linear: Alternative $\gamma = \phi_2$ with $\varepsilon = 0.10$—Investment and Physical Capital

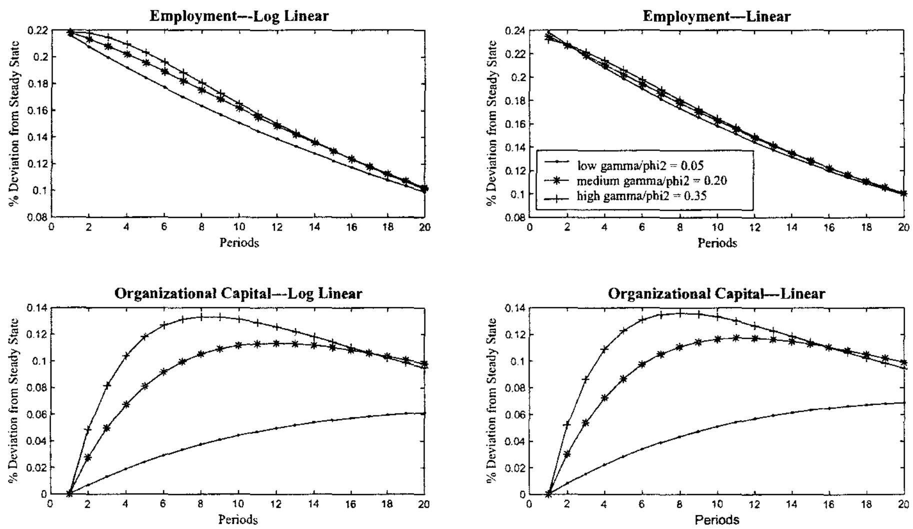

Figure 3.11: Log–Linear & Linear: Alternative $\gamma = \phi_2$ with $\varepsilon = 0.10$—Employment and Organizational Capital

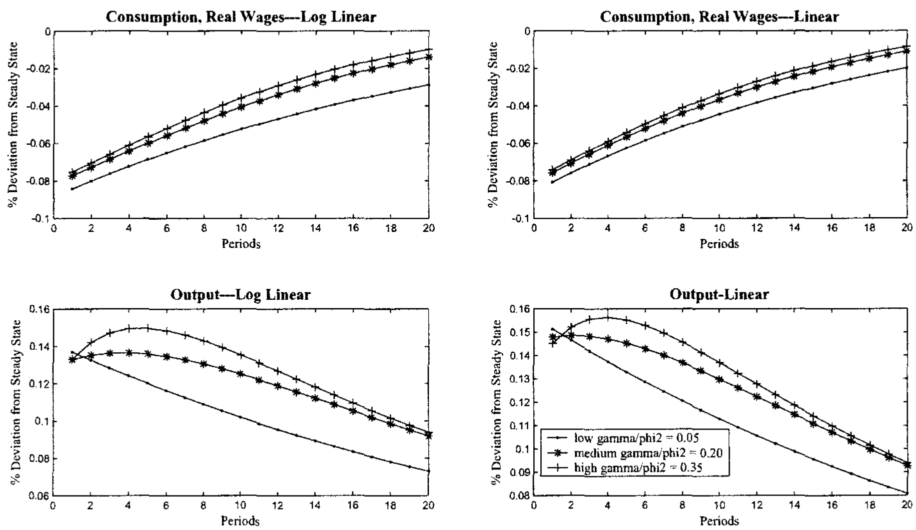

Figure 3.12: Log–Linear & Linear: Alternative $\gamma = \phi_2$ with $\varepsilon = 0.15$—Consumption and Output

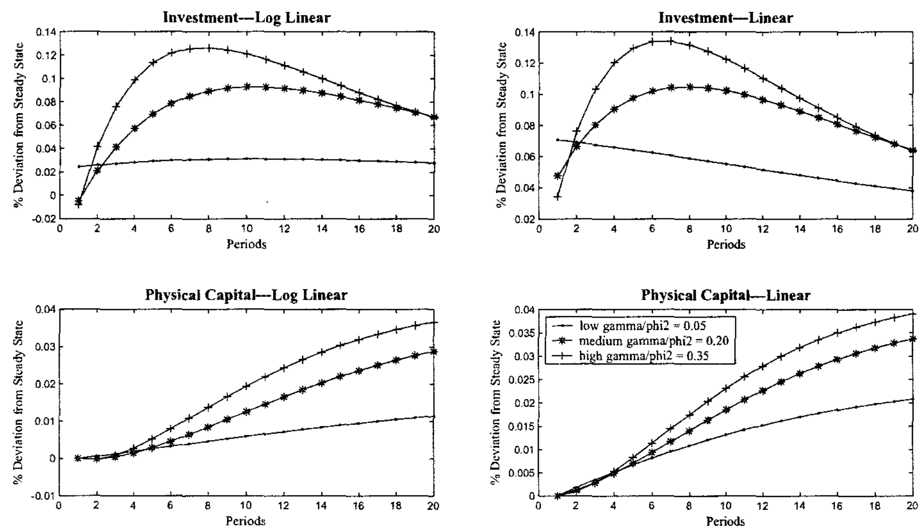

Figure 3.13: Log–Linear & Linear: Alternative $\gamma = \phi_2$ with $\varepsilon = 0.15$—Investment and Physical Capital

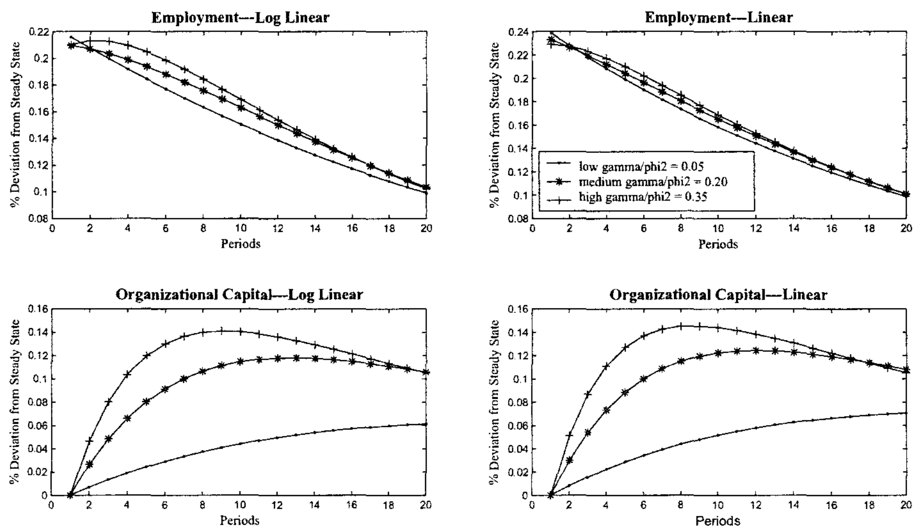

Figure 3.14: Log–Linear & Linear: Alternative $\gamma = \phi_2$ with $\varepsilon = 0.15$—Employment and Organizational Capital

A.3 Appendix: Linear Approximation

A.3.1 No Organizational Capital

$$-\hat{c}_t - \hat{\lambda}_t^h = 0 \tag{A.3.1}$$

$$-\hat{\lambda}_t^h - \psi_2 \, \hat{k}_{t+1} + (1-\psi_2)\, \hat{\lambda}_{t+1}^h + \psi_2 \, \hat{H}_{t+1} - \chi\,(1-\psi_2)\, \hat{\zeta}_{t+1} = 0 \tag{A.3.2}$$

$$\alpha \, \hat{H}_t + \left[\theta + \psi_3 \, \frac{k}{y}\right] \hat{k}_t - \frac{k}{y}\, \hat{k}_{t+1} - \frac{c}{y}\, \hat{c}_t - \frac{g}{y}\, \hat{g}_t - \chi \left[\theta + \psi_3 \, \frac{k}{y}\right] \hat{\zeta}_t = 0 \tag{A.3.3}$$

$$(\alpha - 1)\, \hat{H}_t + \theta \, \hat{k}_t + \hat{\lambda}_t^h - \chi\theta \, \hat{\zeta}_t = 0 \tag{A.3.4}$$

with:

$$\hat{y}_t = \alpha \, \hat{H}_t + \theta \, \hat{k}_t - \chi\theta \, \hat{\zeta}_t \tag{A.3.5}$$

$$\hat{i}_t = \theta \, \frac{y}{i} \hat{k}_t + \alpha \, \frac{y}{i} \hat{H}_t - \frac{c}{y}\,\frac{y}{i}\, \hat{c}_t - \frac{g}{y}\,\frac{y}{i}\, \hat{g}_t - \chi\theta \, \frac{y}{i}\, \hat{\zeta}_t \tag{A.3.6}$$

$$\hat{r}_t^k = \hat{c}_t + \hat{H}_t - \hat{k}_t + \chi \, \hat{\zeta}_t \tag{A.3.7}$$

where:

$$\psi_2 = 1 - [\beta\,(1-\delta)\, \exp(-\chi\psi_x)]$$

$$\psi_3 = (1-\delta)\, \exp(-\chi\psi_x)$$

A.3.2 Log-Linear Accumulation Technology

$$-\hat{c}_t - \hat{\lambda}_t^h = 0 \tag{A.3.8}$$

$$-\hat{\lambda}_t^h - \psi_2\,\hat{k}_{t+1} + (1-\psi_2)\,\hat{\lambda}_{t+1}^h + \psi_2\,\hat{H}_{t+1} - \chi\,(1-\psi_2)\,\hat{\zeta}_{t+1} = 0 \tag{A.3.9}$$

$$\alpha\,\hat{H}_t + \left[\theta + \psi_3\,\frac{k}{y}\right]\,\hat{k}_t + \varepsilon\,\hat{z}_t - \frac{k}{y}\,\hat{k}_{t+1} - \frac{c}{y}\,\hat{c}_t - \frac{g}{y}\,\hat{g}_t - \chi\left[\theta + \psi_3\,\frac{k}{y}\right]\,\hat{\zeta}_t = 0 \tag{A.3.10}$$

$$\begin{aligned}[\alpha - \psi_{41} + \alpha\,\gamma\,\psi_{42}]\;\hat{H}_t + [\theta + \psi_{42}\,\theta\,\gamma]\;\hat{k}_t + [\varepsilon + \psi_{42}(1-\gamma+\varepsilon\,\gamma+\theta\,\gamma)]\;\hat{z}_t \\ + \psi_{41}\,\hat{\lambda}_t^h + \psi_{42}\,\hat{\lambda}_t^f - \chi\,[(\theta+\varepsilon) + \psi_{42}(1-\gamma+\varepsilon\,\gamma+\theta\,\gamma)]\;\hat{\zeta}_t = 0\end{aligned} \tag{A.3.11}$$

$$\begin{aligned}-\,\hat{\lambda}_t^f + [\psi_5 + (1-\psi_5)\,\alpha\,\gamma]\;\hat{H}_{t+1} + (1-\psi_5)\,\theta\,\gamma\,\hat{k}_{t+1} \\ -\,[\psi_5 + (1-\psi_5)\,(1-\gamma+\varepsilon\,\gamma-1)]\;\hat{z}_{t+1} - \psi_5\,\hat{\lambda}_{t+1}^h + (1-\psi_5)\,\hat{\lambda}_{t+1}^f \\ +\,\chi\,[1-(1-\psi_5)\,(1-\gamma+\varepsilon\,\gamma+\theta\,\gamma)]\;\hat{\zeta}_{t+1} = 0\end{aligned} \tag{A.3.12}$$

$$\hat{z}_{t+1} - (1-\gamma+\varepsilon\,\gamma)\,\hat{z}_t - \theta\,\gamma\,\hat{k}_t - \alpha\,\gamma\,\hat{H}_t + \chi\,[1-\gamma+\varepsilon\,\gamma+\theta\,\gamma]\;\hat{\zeta}_t = 0 \tag{A.3.13}$$

with

$$\hat{y}_t = \alpha\,\hat{H}_t + \theta\,\hat{k}_t + \varepsilon\,\hat{z}_t - \chi\,(\theta+\varepsilon)\,\hat{\zeta}_t \tag{A.3.14}$$

$$\hat{i}_t = \theta\,\frac{y}{i}\hat{k}_t + \alpha\,\frac{y}{i}\hat{H}_t + \varepsilon\,\frac{y}{i}\,\hat{z}_t - \frac{c}{y}\,\frac{y}{i}\,\hat{c}_t - \frac{g}{y}\,\frac{y}{i}\,\hat{g}_t - \chi\,(\theta+\varepsilon)\,\frac{y}{i}\,\hat{\zeta}_t \tag{A.3.15}$$

$$\hat{r}_t^k = \hat{c}_t + \hat{H}_t - \hat{k}_t + \chi\,\hat{\zeta}_t \tag{A.3.16}$$

where:

$$\psi_2 = 1 - [\beta\,(1-\delta)\,\exp(-\chi\psi_x)] \qquad \text{and} \qquad \psi_3 = (1-\delta)\,\exp(-\chi\psi_x)$$

$$\psi_{41} = \frac{1 - \beta\exp(\chi\psi_x)\,(1-\gamma)}{1 - \beta\exp(\chi\psi_x)\,(1-\gamma+\varepsilon\,\gamma)}$$

$$\psi_{42} = \frac{\beta\exp(\chi\psi_x)\,\varepsilon\,\gamma}{1 - \beta\exp(\chi\psi_x)\,(1-\gamma+\varepsilon\,\gamma)}$$

$$\psi_5 = 1 - \beta\exp(\chi\psi_x)\,(1-\gamma)$$

A.3.3 Linear Accumulation Technology

$$-\hat{c}_t - \hat{\lambda}_t^h = 0 \tag{A.3.17}$$

$$-\hat{\lambda}_t^h - \psi_2\,\hat{k}_{t+1} + (1-\psi_2)\,\hat{\lambda}_{t+1}^h + \psi_2\,\hat{H}_{t+1} - \chi\,(1-\psi_2)\,\hat{\zeta}_{t+1} = 0 \tag{A.3.18}$$

$$\alpha\,\hat{H}_t + \left[\theta + \psi_3\,\frac{k}{y}\right]\,\hat{k}_t + \varepsilon\,\hat{z}_t - \frac{k}{y}\,\hat{k}_{t+1} - \frac{c}{y}\,\hat{c}_t - \frac{g}{y}\,\hat{g}_t - \chi\left[\theta + \psi_3\,\frac{k}{y}\right]\,\hat{\zeta}_t = 0 \tag{A.3.19}$$

$$\begin{aligned}[\alpha(1+\psi_{42}) - \psi_{41}]\;\hat{H}_t + [\theta(1+\psi_{42})]\;\hat{k}_t + [\varepsilon(1+\psi_{42}]\;\hat{z}_t \\ + \psi_{41}\,\hat{\lambda}_t^h + \psi_{42}\,\hat{\lambda}_t^f - \chi\,[(\theta+\varepsilon)(1+\psi_{42})]\;\hat{\zeta}_t = 0\end{aligned} \tag{A.3.20}$$

$$\psi_5\, \hat{H_{t+1}} - \psi_5, \hat{z_{t+1}} - \psi_5\, \lambda^{\hat{h}}_{t+1} + (1-\psi_5)\, \lambda^{\hat{f}}_{t+1} + \chi\psi_5\, \hat{\zeta}_{t+1} = 0 \tag{A.3.21}$$

$$\hat{z}_{t+1} - [\psi_6 + \varepsilon(1-\psi_6)]\ \hat{z}_t - \theta(1-\psi_6)\, \hat{k}_t \\ - \alpha(1-\psi_6)\, \hat{H}_t + \chi\, [\psi_6 + (\theta+\varepsilon)\,(1-\psi_6)]\ \hat{\zeta}_t = 0 \tag{A.3.22}$$

with

$$\hat{y}_t = \alpha\, \hat{H}_t + \theta\, \hat{k}_t + \varepsilon\, \hat{z}_t - \chi\,(\theta+\varepsilon)\, \hat{\zeta}_t \tag{A.3.23}$$

$$\hat{i}_t = \theta\, \frac{y}{i} \hat{k}_t + \alpha\, \frac{y}{i} \hat{H}_t + \varepsilon\, \frac{y}{i}\, \hat{z}_t - \frac{c}{y}\, \frac{y}{i}\, \hat{c}_t - \frac{g}{y}\, \frac{y}{i}\, \hat{g}_t - \chi\,(\theta+\varepsilon)\, \frac{y}{i}\, \hat{\zeta}_t \tag{A.3.24}$$

$$\hat{r}^k_t = \hat{c}_t + \hat{H}_t - \hat{k}_t + \chi\, \hat{\zeta}_t \tag{A.3.25}$$

where:

$$\psi_2 = 1 - [\beta\,(1-\delta)\ \exp(-\chi\psi_x)] \qquad \text{and} \qquad \psi_3 = (1-\delta)\ \exp(-\chi\psi_x)$$

$$\psi_{41} = \frac{1-\beta\phi_1}{1-\beta\phi_1 - \beta\varepsilon\exp(\chi\psi_x) + \beta\varepsilon\phi_1} \qquad \text{and}$$

$$\psi_{42} = \frac{\beta\varepsilon\exp(\chi\psi_x) - \beta\varepsilon\phi_1}{1-\beta\phi_1 - \beta\varepsilon\exp(\chi\psi_x) + \beta\varepsilon\phi_1}$$

$$\psi_5 = 1 - \beta\phi_1 \qquad \text{and} \qquad \psi_6 = \phi_1 \exp(-\chi\psi_x)$$

4 Organizational Capital and Plant Level Productivity

4.1 Introduction

The previous two chapters have detailed some implications for the aggregate economy arising from the accumulation of organizational capital and in particular from the accumulation of organizational capital by production units. It has been shown that the accumulation of organizational capital (by production units) introduces an important dynamic structure into the choice problem of production units that is capable of generating an internal propagation mechanism, beyond that associated with physical capital accumulation.

A key component of this dynamic structure is the existence of an accumulation technology for organizational capital intended to capture some general features of the stock of organizational capital available to production units. This accumulation technology is consistent with the hypothesis of organizational forgetting so that relatively distant production experience becomes less relevant over time.

The results presented in Chapter 3 reveal that the dynamic response of the aggregate economy to a temporary, unanticipated fiscal shock depends critically upon the values of the structural parameters associated with the accumulation of organizational capital. This suggests that it will be important to obtain reliable estimates of these parameters, in order to fully evaluate the aggregate implications of allowing for the accumulation of organizational capital and provide reliable policy conclusions. A necessary first step in providing these policy conclusions requires an (empirical) evaluation of the dynamic structure associated with the accumulation of organizational capital.

Although there is a well established empirical literature that explores the relationship between production experience and plant productivity, there are relatively few studies that explore this relationship allowing for the depreciation of production experience. Argote et al. (1990) provide empirical evidence for this hypothesis of organizational forgetting associated with the construction of Liberty Ships during World War II, and Benkard (2000) provides evidence for this hypothesis associated with the production of commercial aircraft. This focus upon specific organizations is primarily dictated by the stringent requirements that researchers observe the entire history of production rates since the birth of production units. Unfortunately, these studies are subject to the familiar biases associated with the estimation of production technology parameters from production or cost functions. These particular biases are detailed in the next section.

In contrast, both Cooper & Johri (2002) and Johri & Letendre (2002) are able to provide evidence for this hypothesis using more aggregated data by using a log-linear specification for the accumulation technology. This log-linear specification implies that the structural parameters associated with the accumulation of organizational capital might be estimated without the need for knowledge of the stock of organizational capital. However, the use of aggregate data implicitly imposes some strong restrictions on the structural model that allows for the aggregation of potentially heterogenous production units. Intuitively, this aggregation is achieved by restricting attention to competitive equilibria that may be formulated as a choice problem solved by a social planner. Chapters 2 and 3 have considered a decentralized version of the Cooper & Johri (2002) model with imperfect competition such that the competitive allocations need not coincide with the allocations of the planning solution. In this case, by restricting attention to the symmetric equilibrium in which all producers charge the same (relative) price, the demand system allows for the aggregation of the stock of organizational capital for individual production units.

A robust finding from existing studies is that plant level productivity distributions are typically characterized by considerable heterogeneity both between and within narrowly defined industry classifications.[1] Consequently, estimates of the structural parameters associated with the accumulation of organizational capital using aggregate data need not coincide with estimates of these parameters using data collected at the plant level. This chapter utilizes a lengthy panel of annual observa-

[1] Jensen et al. (2001)

tions for a large cross section of Canadian manufacturing establishments to provide some estimates of these structural parameters. As such it provides a bridge between the specific evidence in Argote et al. (1990) and Benkard (2000) and the aggregate evidence presented in Cooper & Johri (2002) and Johri & Letendre (2002).

Rather than directly estimating the production function (or the cost function), this chapter presents estimates using the first order conditions from structural model of organizational capital. This chapter also provides a method for estimating the contribution of organizational capital to plant level productivity using available plant level census data, while at the same time avoiding some of the commonly identified problems associated with the estimation of learning effects from production functions.

The results presented in this chapter suggest that the dynamic structure, associated with the accumulation of organizational capital, might be consistent with the plant level data. In addition, this dynamic structure is likely to be empirically important for production units across a diverse range of (manufacturing) industries. Consequently, existing studies of learning-by-doing that aim to quantify the productivity of (accumulated) production experience without also considering the (endogenous) accumulation of this production experience are likely to be seriously flawed.

4.2 Previous Research and Motivation

The conventional study of learning-by-doing considers the following production function:

$$Q_{it} = A_{it}\, K_{it}^{\theta}\, H_{it}^{\alpha} \tag{1}$$

where Q_{it} represents output, H_{it} is the labour input, K_{it} is the physical capital input and the level of technology A_{it} is given by:

$$A_{it} = A_{i0}\, \exp(\lambda\, t)\, Z_{it}^{\varepsilon}\, \exp(\omega_{it}) \qquad \text{and} \qquad Z_{it} = \sum_{j=s}^{t-1} Q_{ij}$$

where Z_{it} is production experience represented by cumulative output since the birth of the production unit, and the term $A_{i0}\, \exp(\lambda\, t)$ represents exogenous technical change. The term ω_{it} represents the unobserved portion of productivity.

This provides the following estimating equation:

$$\ln Q_{it} = \ln A_{i0} + \lambda\, t + \theta \ln K_{it} + \alpha \ln H_{it} + \varepsilon \ln Z_{it} + \omega_{it}$$

where ω_{it}, is assumed to be an independently and identically distributed disturbance term that is (assumed) independent of H_{it}, K_{it} and Z_{it}. The production technology (1) provides the following unit cost function:

$$\frac{C(Q_{it}, w_t, r_t, A_{it}, Z_{it})}{Q_{it}} = \frac{\alpha+\theta}{\alpha}\left[\left(\frac{\alpha}{\theta}\right)^{\theta} Q_{it}^{1-\alpha-\theta}\,[A_{i0}\,\exp(\lambda\, t)]^{-1}\, Z_{it}^{-\varepsilon}\, w_t^{\alpha}\, r_t^{\theta}\right]^{(\alpha+\theta)^{-1}}$$

The conventional learning curve model assumes constant returns to scale in labour and physical capital so that the unit cost function is independent of the level of output. The learning rate is defined as the percentage reduction in unit costs associated with a doubling of production experience. Formally, assuming that factor prices are independent of the stock of organizational capital, the learning rate is given by $LR = 1 - 2^{-\varepsilon}$.

There are several reasons to expect that estimation of the production technology (1) or the learning curve will provide biased estimates of the learning parameter ε. Firstly, the physical capital input might be measured with considerable error so that the estimates of θ might be biased towards zero. In this case, the estimate of ε and α will also be biased.

Generally, it is the value of output rather than the quantity of output that is available in commonly used datasets. In this case it is usual to construct a series for output by deflating this revenue variable by an appropriate industry level deflator. Denoting the (unobserved) level of output by Q_{it}^*, output is constructed according to:

$$Q_{it} = \frac{R_{it}}{P_t} = \frac{Q_{it}^* v_{it}}{P_t} \qquad \text{or} \qquad \ln Q_{it} = \ln R_{it} - lnP_t = \ln Q_{it}^* + \ln v_{it} - \ln P_t$$

so that the observed output level will differ from the true output level to the extent that plant-specific prices differ from the industry average.[2] This implies that:

$$\ln Q_{it} = \ln A_{i0} + \lambda t + \theta \ln K_{it} + \alpha\ \ln H_{it} + \ln v_{it} - \ln P_t + \omega_{it}$$

[2]This can be seen by noting $\ln Q_{it} - \ln Q_{it}^* = \ln v_{it} - \ln P_t$.

or

$$R_{it} = \ln A_{i0} + \lambda t + \theta \ln K_{it} + \alpha \ln H_{it} + (\ln v_{it} + \omega_{it})$$

As shown by Klette & Griliches (1996), measuring output as deflated total revenues introduces a form of omitted variable bias where the omitted plant-specific price will be reflected in the residual ω_{it}. Consequently, if this omitted price variable is correlated with the included variables in (1), an omitted variable bias might arise. This will be particularly important when production units operate in imperfectly competitive product markets. For example, consider a production unit that receives a large, idiosyncratic productivity shock. Provided output demand is sufficiently elastic, this productivity shock will be associated with a lower output price and increased quantities of the productive inputs. All else equal, this will reduce estimates of α and θ.

This problem with using deflated revenues to measure the level of output becomes relatively more serious when estimating the learning curve. In this case:

$$Z_{it} = \sum_{j=s}^{t-1} Q^*_{ij} = \sum_{j=s}^{t-1} \frac{Q_{it} P_t}{v_{it}} = \sum_{j=s}^{t-1} \frac{R_{it}}{v_{it}}$$

so that the (observable) stock of production experience will be subject to measurement error associated with the unobservable plant-specific price.

Both the physical capital input and the labour input are likely to be endogenous to the production decision. Consider a production unit that receives a positive productivity shock, represented by a relatively large realization of ω_{it}. This will increase labour demand and consequently the labour input which leads to a positive correlation between the labour input and the unobserved productivity term. All else equal, α and θ, will tend to be overestimated relative to their true values. As noted by Olley & Pakes (1996), this problem is likely to be more severe, the easier it is to adjust inputs in response to current realizations of productivity.

The results presented in Olley & Pakes (1996) indicate that there might be considerable serial correlation in the unobserved component of productivity. This suggests the assumption that ω_{it} be independently and identically distributed may be inappropriate. Moreover, in this case, the stock of experience will likely be correlated with ω_{it}. The stock of production experience Z_{it} will be a function of past output, which is a function of past realizations of productivity and thus past values of ω_{it}. Since these past values of ω_{it} will be correlated with current values of ω_{it}, the stock of experience will be correlated with the current realization of ω_{it}.

The traditional studies of learning-by-doing do not control for the quality of the productive inputs of labour and physical capital which might represent an omitted variable bias. For example, if skilled labour and physical capital were complements, so that the physical capital input were positively correlated with the omitted human capital variable, estimates of θ are likely to be biased upwards. This issue is addressed by Bahk & Gort (1993) who extend the traditional study of learning-by-doing by introducing human capital (measured by the average wage rate) and the average vintage of physical capital as arguments in the production function, separate from raw labour and the physical capital. Their results suggest that a large portion of the traditional 20% learning rates might be associated with embodied input augmenting technical change.

Beyond these sources of potential bias associated with estimation of the traditional learning curve, there is considerable empirical evidence that the stock of experience might be subject to some form of organizational forgetting.[3] In this case, cumulative output since birth is not an appropriate measure of the stock of production experience. This chapter presents a method for estimating learning effects, allowing for the depreciation of production experience, that also addresses some of these sources of bias associated with traditional estimates of learning-by-doing effects.

Rather than directly estimating the production function (or the cost function), this chapter presents estimates using the first order conditions from a (well-specified) structural model of organizational capital. Consistent with the interpretation of production experience in this thesis, this structural model focuses upon production experience that is accumulated and stored by the production unit. This implies that the (optimal) decision of how much output to produce will actually be a joint decision on how much organizational capital to accumulate.

The approach in this chapter differs considerably from existing studies by explicitly considering market structure. The accumulation of organizational capital

[3] See, for example, Argote et al. (1990) or Benkard (2000)

in the presence of imperfectly competitive product markets introduces an important dynamic structure into the optimization problem of production units. Treating the stock of organizational capital as a productivity enhancing factor of production implies that the accumulation of production experience might be associated with a production technology that exhibits increasing returns to scale. In this case, it is inappropriate to assume that production units operate in a perfectly competitive product market. Consequently, the accumulation of production experience cannot be studied without also considering market structure. Specifically, when these production units face a downward sloping demand curve for their product, they recognize that charging a higher price today results in less output being sold. However, this lower output will also result in a lower stock of production experience in the future with consequently higher future costs of production. Fundamentally, these production units face a trade-off between maximizing current period profits and losing future productivity increases. The failure of existing studies to account for this dynamic structure is likely to produce considerably biased estimates of the learning rate.

It is shown that the assumption of a (Cobb-Douglas) production technology and a log-linear accumulation technology implies that estimates of the structural parameters of interest might be obtained without the need for data on both the physical capital input and the stock of organizational capital. This approach avoids problems associated with the measurement of both this physical capital input and the stock of production experience. In particular, the estimation does not require data on the stock of organizational capital, so that there is no need to track production units from their birth. Consequently, this chapter uses a lengthy panel of annual observations for a large cross section of manufacturing establishments. This provides a bridge between the microeconomic evidence for learning-by-doing in specific industries and organizations and the aggregate results of Cooper & Johri (2002) and Johri & Letendre (2002) while at the same time using data collected at the plant level.

Secondly, the estimating equation requires data on total revenues rather than the level of output which avoids the problems, identified by Klette & Griliches (1996), associated with the use of deflated total revenues to measure the level of output. Finally, rather than directly estimating the production function (or the cost function), this chapter presents estimates of the first order conditions from a well-specified structural model of organizational capital. This avoids the problems associated with the correlation of production experience, physical capital, and labour with the unobserved component of plant productivity.

4.3 A Model of Plant Behaviour with Organizational Capital

The structural model used in this chapter corresponds to that portion of the structural model, detailed in Chapter 2, related to the production side of the model economy. Consider a plant i operating within a monopolistically competitive industry that produces an intermediate good Q_{it} using the following production technology:

$$Q_{it} = A_{it} F(K_{it}, H_{it}, M_{it}, Z_{it}) \tag{2}$$

where organizational capital Z_{it} is combined with physical capital K_{it}, the human capital input H_{it} and intermediate inputs M_{it} to produce output Q_{it}. Note that these intermediate inputs M_{it} represent inputs to the production of the intermediate good Q_{it}. The stock of organizational capital is predetermined in the sense that Z_{it} reflects the stock of organizational capital chosen at time $t-1$. The term A_{it} is an exogenous shock to total factor productivity.[4] The production technology (2) exhibits positive and diminishing marginal productivity with respect to each input.

Organizational capital is accumulated according to:

$$Z_{i,t+1} = G(Z_{it}, Q_{it}) \tag{3}$$

where $G(\cdot)$ is increasing in both of its arguments. This accumulation equation may be viewed as a technology that uses the existing stock of organizational capital and current plant output as productive inputs.

The demand system for final goods, outlined in Chapter 2, provides the fol-

[4]The estimation results will not critically depend upon whether the unobserved component of productivity is modelled as a total factor productivity shock or as a shock to the level of labour-augmenting technical progress.

lowing inverse demand function for the producer of intermediate good i:

$$v_{it}(Q_{it}, P_t, Y_t) = \left\{ \frac{Q_{it}}{Y_t} \right\}^{\frac{1-\mu}{\mu}} P_t \tag{4}$$

where v_{it} is the output price, Y_t represents the output of the final goods sector and P_t is the equilibrium price of the final good. Using (4), the price elasticity of demand is given by $\mu/(1-\mu)$, the negative of the elasticity of substitution between any two intermediate inputs in final goods production.

It is useful to dissect the problem faced by an intermediate goods producer into two stages. In the first stage, the producer chooses the cost minimizing quantities of labour H_{it}, physical capital K_{it}, and intermediate inputs M_{it}, for a given stock of organizational capital, following the realization of the shock A_{it}. Since productive factors are assumed to be perfectly mobile, the intermediate goods producer i solves the following static cost minimization problem:

$$\min_{H_{it}, K_{it}, M_{it}} \{ w_t \cdot H_{it} + r_t \cdot K_{it} + s_t \cdot M_{it} \mid F(A_{it}, K_{it}, H_{it}, M_{it}, Z_{it}) \geq Q_{it} \} \tag{5}$$

Each intermediate goods producer is assumed to operate within a perfectly competitive input market such that the (real) rental price of physical capital r_t; the (real) wage w_t and the (real) price of intermediate inputs s_t are taken as given.

The cost minimization problem produces conditional factor demands that are a function of factor prices, the required level of output (Q_{it}) and the stock of organizational capital (Z_{it}).

In the second stage, the intermediate goods producer will solve a dynamic problem that selects the time path of output supply Q_{it} or output price v_{it} that maximizes the expected discounted present value of profits, subject to the inverse demand function (4), the accumulation technology for organizational capital (3), and the initial stock of organizational capital Z_{i0}. The initial stock of organizational capital Z_{i0} constitutes the inherited knowledge of the organization which might include a common component reflecting the prevailing best practice systems, structures and procedures and an idiosyncratic component reflecting the more context specific knowledge imparted by the organizations founders that becomes a durable feature of the organization. There is no entry or exit by assumption so that the number of intermediate goods producers remains fixed.

Each intermediate producer faces the following demand function:

$$Q_{it} = f(v_{it}, P_t, Y_t) = \left\{ \frac{v_{it}}{P_t} \right\}^{\mu/(1-\mu} Y_t$$

Using this demand function, the Lagrangian associated with the maximization problem of the *ith* producer of intermediate goods will be given by:

$$\max_{v_t, z_{t+1}} E_0 \sum_{t=0}^{\infty} \Big[\beta^t \left[v_t \cdot f(v_t, P_t, Y_t) - P_t \cdot C(w_t, r_t, X_t, f(v_t, P_t, Y_t), Z_t) \right] \\ + \Lambda_t^f \left\{ G\left[Z_t, f(v_t, P_t, Y_t) \right] - Z_{t+1} \right\} \Big]$$

subject to the transversality condition $\lim_{t \to \infty} \Lambda_{it} Z_{it} = 0$. The parameter β is a (common) discount factor satisfying $0 < \beta < 1$ and $\beta = 1/(1 + \rho)$ where ρ is the rate of time preference. This discount factor β is assumed not to vary across the intermediate goods producers.

The stochastic nature of the problem arises because the producer must choose their (desired) stock of organizational capital prior to the realization of the technology shock A_{t+1}. Expectations are assumed to be formed rationally so that E_t denotes both the mathematical expectation at time t and the subjective expectation at time t. It is assumed that all past and current realizations of the exogenous and control variables are known with certainty at the beginning of each period but there is uncertainty regarding future realizations of the exogenous variables. Specifically, expectations are formed, conditional upon the information set Ω_t which includes the realizations of the exogenous variables and the endogenous state variable Z_t:

$$\Omega_{it} = [A_{it}, v_{it}, w_t, r_t, P_t, Y_t, Z_{it}]$$

Consequently, at time 0, the producer will have the information set Ω_0. The solution to this maximization problem will satisfy the following first order conditions (for all

t):

$$\left[Q_{it} + v_{it}\,\frac{\partial Q_{it}}{\partial v_{it}}\right] - P_t\,\frac{\partial C_{it}}{\partial Q_{it}}\,\frac{\partial Q_{it}}{\partial v_{it}} + \frac{\Lambda_{it}}{\beta^t}\,\frac{\partial Z_{i,t+1}}{\partial Q_{it}}\,\frac{\partial Q_{it}}{\partial v_{it}} = 0 \qquad (6)$$

and

$$-\frac{\Lambda_{it}}{\beta^t} - \beta\,E_t\left\{P_{t+1}\,\frac{\partial C_{i,t+1}}{\partial Z_{i,t+1}} - \frac{\Lambda_{t+1}}{\beta^{t+1}}\,\frac{\partial Z_{i,t+2}}{\partial Z_{i,t+1}}\right\} = 0 \qquad (7)$$

The first order condition (6) determines the optimal output price v_{it} to be set by the producer of the intermediate input i. Since the intermediate goods producer faces a downward sloping demand curve for their product, raising the output price by one unit causes demand for their product to fall. The first term in (6) captures the impact on current revenue of raising the price of output v_{it}. The second term represents the reduction in current period costs resulting from the corresponding lower level of output. The accumulation technology for organizational capital implies that a reduction in current output will lead to a reduction in the stock of organizational capital available in the next period. The final term in (6) represents the value of this reduced (future) stock of organizational capital. The term $\partial Q_{it}/\partial v_{it}$ measures the reduction in current output due to the higher output price and the term $\partial Z_{i,t+1}/\partial Q_{it}$ represents the reduction in the stock of organizational capital resulting from the reduction in current period output, evaluated at the marginal value of organizational capital to the intermediate goods producer.

The first order condition (6) captures the nature of the dynamic trade-off that arises when intermediate goods producers faces a downward sloping demand curve. Fundamentally, these producers face a trade-off between maximizing current period profits and losing future productivity increases. This tradeoff is captured by the (dynamic) third term in (6) that will not appear in the standard model of monopolistic competition without the accumulation of organizational capital.

The first order condition (7) determines the value of an additional unit of organizational capital for use by the producer in period $t+1$. This additional unit of organizational capital has a (marginal) value, in terms of profits, of Λ_{it}/β^t to the producer. Since the cost function is decreasing in the stock of organizational capital, an additional unit of organizational capital reduces the cost of producing output level $Q_{i,t+1}$. The accumulation equation for organizational capital implies that an additional unit of organizational capital will increase the stock of organizational capital available in period $t+2$. This higher stock of organizational capital has a value of $\Lambda_{i,t+1}/\beta^{t+1}$ to the producer. The condition (7) implies that organizational capital will be accumulated up to the point where the value of an additional unit of organizational capital today is equal to the discounted value of this organizational capital next period.

4.3.1 Some Functional Forms

The first order conditions (6) and (7) cannot be estimated without specifying some functional forms for the production technology (2) and the accumulation technology (3). The choice of functional form is driven primarily by the nature of the plant level data currently available. In addition, these functional forms have been chosen to allow a comparison with both existing microeconomic studies of production experience and the work of Cooper & Johri (2002) and Johri & Letendre (2002).

Assume the production technology (2) takes the following form:[5]

$$Q_{it} = A_{it}\, K_{it}^{\theta}\, H_{it}^{\alpha}\, M_{it}^{\phi}\, Z_{it}^{\varepsilon} \qquad \alpha > 0, \theta > 0, \phi > 0, \varepsilon > 0. \tag{8}$$

The minimized cost function becomes:

$$C_{it}(w_t, r_t, s_t, A_{it}, Q_{it}, Z_{it}) = f(\alpha, \theta\phi) \left[\frac{Q_{it}}{A_{it}}\, w_t^{\alpha}\, r_t^{\theta}\, s_t^{\phi}\, Z_{it}^{-\varepsilon}\right]^{1/k} \tag{9}$$

where $k = \alpha+\theta+\phi$ and $f(\alpha, \theta, \phi)$ is a non-linear function of the production technology

[5] All of the previous studies of production experience use a Cobb-Douglas form for the production technology.

parameters. This cost function provides the following (optimal) input demands:

$$H^*_{it}(w_t, r_t, s_t, A_{it}, Q_{it}, Z_{it}) = \frac{\alpha}{\alpha+\theta+\phi}\,\frac{C_{it}(w_t, r_t, s_t, A_{it}, Q_{it}, Z_{it})}{w_t}$$

$$K^*_{it}(w_t, r_t, s_t, A_{it}, Q_{it}, Z_{it}) = \frac{\theta}{\alpha+\theta+\phi}\,\frac{C_{it}(w_t, r_t, s_t, A_{it}, Q_{it}, Z_{it})}{r_t}$$

$$M^*_{it}(w_t, r_t, s_t, A_{it}, Q_{it}, Z_{it}) = \frac{\phi}{\alpha+\theta+\phi}\,\frac{C_{it}(w_t, r_t, s_t, A_{it}, Q_{it}, Z_{it})}{s_t}$$

Let the accumulation equation for organizational capital (3) be given by the following log-linear specification:

$$Z_{i,t+1} = Z_{it}^{\eta}\, Q_{it}^{\gamma} \tag{10}$$

This log-linear specification for the accumulation technology might be motivated in several ways. Firstly, it facilitates a comparison of the structural estimates provided in this chapter with those provided in Cooper & Johri (2002) and Johri & Letendre (2002), based upon aggregate data. Secondly, as discussed below, this log-linear specification allows the structural parameters to be identified from available plant level census data. Finally, the results presented in Chapters 2 and 3 suggest that, the macroeconomic implications of allowing for the accumulation of organizational capital according to a log-linear technology may not be considerably different than those associated with a linear technology.

Define the multiplier $\lambda_{it} = \Lambda_{it}/\beta^t$. Using these functional forms, the first order conditions may be written as:

$$v_{it}\cdot Q_{it} - \frac{\mu}{\alpha+\theta+\phi}\, P_t\, C_{it} + \lambda_{it}\,\gamma\mu\, Z_{i,t+1} = 0 \tag{11}$$

and

$$\lambda_{it} + \beta\, E_t \left\{ \frac{\varepsilon}{\alpha+\theta+\phi}\,\frac{P_{t+1}\, C_{i,t+1}}{Z_{i,t+1}} + \eta\, \lambda_{i,t+1}\, \frac{Z_{i,t+2}}{Z_{i,t+1}} \right\} = 0 \tag{12}$$

Using (11) to substitute for the multiplier λ_{it}, these first order conditions imply the following dynamic equation:

$$\frac{1}{\gamma\mu}\frac{v_{it}Q_{it}}{Z_{i,t+1}} - \frac{1}{\gamma}\frac{1}{\alpha+\theta+\phi}\frac{P_t C_{it}}{Z_{i,t+1}}$$

$$+\beta\, E_t \left\{ \frac{\varepsilon}{\alpha+\theta+\phi}\frac{P_{t+1}C_{i,t+1}}{Z_{i,t+1}} - \frac{\eta}{\gamma\mu}\frac{v_{i,t+1}Q_{i,t+1}}{Z_{i,t+1}} + \frac{\eta}{\gamma}\frac{1}{\alpha+\theta+\phi}\frac{P_{t+1}C_{i,t+1}}{Z_{i,t+1}} \right\} = 0$$

This can be further simplified by noting that $Z_{i,t+1}$ is chosen at time t and is known with certainty at the beginning of period $t+1$. Using the optimality condition from the cost minimization problem which requires that the (real) wage bill be proportional to (real) total cost, this equation may be written as:

$$E_t \left\{ \frac{\alpha}{\mu}\frac{v_{it}Q_{it}}{P_t w_t H^*_{it}} + \beta\,[\varepsilon\gamma+\eta]\,\frac{P_{t+1}w_{t+1}H^*_{i,t+1}}{P_t w_t H^*_{it}} - \beta\,\eta\,\frac{\alpha}{\mu}\frac{v_{i,t+1}Q_{i,t+1}}{P_t w_t H^*_{it}} - 1 \right\} = 0 \qquad (13)$$

where H^*_{it} is the cost minimizing labour input. Alternatively, using the optimality condition from the cost minimization problem which requires that the (real) cost of intermediate inputs be proportional to (real) total cost, this equation may be written as:

$$E_t \left\{ \frac{\phi}{\mu}\frac{v_{it}Q_{it}}{P_t s_t M^*_{it}} + \beta\,[\varepsilon\gamma+\eta]\,\frac{P_{t+1}s_{t+1}M^*_{i,t+1}}{P_t s_t M^*_{it}} - \beta\,\eta\,\frac{\phi}{\mu}\frac{v_{i,t+1}Q_{i,t+1}}{P_t s_t M^*_{it}} - 1 \right\} = 0 \qquad (14)$$

where M^*_{it} is the cost minimizing quantity of intermediate inputs. Since the optimality condition from the cost minimization problem requires:

$$\frac{w_t \cdot H^*_{it}(w_t, r_t, s_t, A_{it}, Q_{it}, Z_{it})}{s_t \cdot M^*_{it}(w_t, r_t, s_t, A_{it}, Q_{it}, Z_{it})} = \frac{\alpha}{\phi}$$

the dynamic equation (13) may be written as:

$$E_t \left\{ \frac{\phi}{\mu}\frac{v_{it}Q_{it}}{P_t s_t M^*_{it}} + \beta\,[\varepsilon\gamma+\eta]\,\frac{P_{t+1}w_{t+1}H^*_{i,t+1}}{P_t w_t H^*_{it}} - \beta\,\eta\,\frac{\phi}{\mu}\frac{v_{i,t+1}Q_{i,t+1}}{P_t s_t M^*_{it}} - 1 \right\} = 0 \qquad (15)$$

and (14) may be written as:

$$E_t \left\{ \frac{\alpha}{\mu} \frac{v_{it} Q_{it}}{P_t w_t H_{it}^*} + \beta \left[\varepsilon\gamma + \eta \right] \frac{P_{t+1} s_{t+1} M_{i,t+1}^*}{P_t s_t M_{it}^*} - \beta\eta \frac{\alpha}{\mu} \frac{v_{i,t+1} Q_{i,t+1}}{P_t w_t H_{it}^*} - 1 \right\} = 0 \qquad (16)$$

Note that (15) and (16) are equivalent expressions of the first order conditions arising from the production unit's maximization problem.

It is clear from (15) or (16) that the choice of functional form for both the production technology and the accumulation technology greatly simplify the estimation of the first order conditions for the structural model. Estimates of the structural parameters of interest may be obtained without the need for data on both the physical capital input and the stock of organizational capital. The Cobb-Douglas production technology provides a cost function that is proportional to the wage bill so there is no need for data on the physical capital input which will be measured with error. More importantly, the log-linear accumulation technology implies that the first order condition does not require data on the stock of organizational capital. This significantly reduces the data requirements since there is no need for data on the entire history of output since birth. This avoids the need to track entrants from birth. Finally, note that the dynamic equation (15) or (16) implies that the structural parameters of interest might be estimated using data on total revenues rather than requiring data on the level of output.

4.4 Empirical Estimation Strategy

The driving force behind the dynamic structure of the model are the parameters η, γ and ε. It is possible to obtain estimates of these parameters without estimating the full structural model. Using the Generalized Method of Moments (GMM), consistent estimates of the parameters may be obtained by directly estimating the dynamic equation given by (15) or (16).[6] In contrast to estimation of the full structural model, say by maximum likelihood methods, this avoids the need to specify the distribution of the random variable A_{it}.

An examination of the dynamic equation (15) or (16) reveals that only a subset of the parameter set (ϕ, μ, β, η, γ, ε) or (α, μ, β, η, γ, ε) will be identified.

[6] The estimation uses the GMM code written in MATLAB by Mike Cliff of Purdue University.

Firstly, only estimates of the ratio ϕ/μ or α/μ may be obtained so that the demand parameter μ and the productivity parameters α or ϕ cannot be separately identified. Although, it is possible to obtain estimates of η by directly estimating the product $\varepsilon\gamma$, ε and γ cannot be separately identified. Since ε is also a parameter of interest, a more appropriate solution would impose constant returns to scale in the accumulation technology ($\gamma = 1-\eta$) so that separate estimates of ε and η (or γ) might be obtained.[7] In addition only two of the parameters β, η and ε will be identified. Rather than estimating the discount rate β, it is calibrated to $\beta = 0.9627$, the annual equivalent of the Bank of Canada 90 day Commercial Paper rate, for the period covered by the data.[8]

It is convenient to write the equation (15) or (16) in terms of period t dated variables rather than $t+1$ dated variables:

$$E_{t-1}[h(W_{it}, \Phi_0) \mid \Omega_{i,t-1}] = 0$$

where $\Omega_{i,t-1}$ denotes the information set available to production unit i in period $t-1$. Using the dynamic equation (15):

$$h(W_{it}, \Phi_0) = \frac{\phi}{\mu} \frac{v_{i,t-1}Q_{i,t-1}}{P_{t-1}s_{t-1}M^*_{i,t-1}} + \beta\left[\varepsilon\gamma + \eta\right] \frac{P_t w_t H^*_{it}}{P_{t-1}w_{t-1}H^*_{i,t-1}} - \beta\,\eta\,\frac{\phi}{\mu} \frac{v_{it}Q_{it}}{P_{t-1}s_{t-1}M^*_{i,t-1}} - 1$$

or using (16):

$$h(W_{it}, \Phi_0) = \frac{\alpha}{\mu} \frac{v_{i,t-1}Q_{i,t-1}}{P_{t-1}w_{t-1}H^*_{i,t-1}} + \beta\left[\varepsilon\gamma + \eta\right] \frac{P_t s_t M^*_{it}}{P_{t-1}s_{t-1}M^*_{i,t-1}} - \beta\,\eta\,\frac{\alpha}{\mu} \frac{v_{it}Q_{it}}{P_{t-1}w_{t-1}H^*_{i,t-1}} - 1$$

where Φ_0 is a vector of unknown structural parameters. Define the forecast error e_{it} as the difference between the actual realizations of the endogenous variables and their

[7]Chapter 2 contains a discussion as to why it might be appropriate to impose constant returns to scale in the accumulation technology.

[8]At the quarterly frequency, this discount rate is quite close to the (calibrated) value of β used in Chapters 2 and 3. The value of β used in Chapters 2 and 3 is based upon aggregate data for the U.S. economy over a much larger period whereas a discount rate of $\beta = 0.9627$ is based upon data for the aggregate Canadian economy over the sample period covered by the Canadian data used in this chapter. Alternative calibrated values for β have relatively little impact upon the structural estimates.

conditional expectation:

$$e_{it} = h(W_{it}, \Phi_0) - E_{t-1}[h(W_{it}, \Phi_0) \mid \Omega_{i,t-1}] = h(W_{it}, \Phi_0)$$

where $E_{t-1}[e_{it} \mid \Omega_{i,t-1}] = 0$ for all t. The hypothesis of rational expectations requires the errors e_{it} that agents make in forecasting be uncorrelated with any of the information available at the time of the forecast. Let the econometrician observe the $P \times 1$ vector $S_{i,t-1}$, which is a subset of the information set $\Omega_{i,t-1}$. The law of iterated expectations provides the following:

$$E_{t-1}[e_{it} \mid S_{i,t-1}] = E_{t-1}\left\{E_{t-1}[e_{it} \mid \Omega_{i,t-1}] \mid S_{i,t-1}\right\} = 0$$

which provides the following unconditional expectation

$$E[S_{i,t-1}\, e_{it}] = E\left\{E_{t-1}[S_{i,t-1}\, e_{it} \mid S_{i,t-1}]\right\} = E[S_{i,t-1}\, E_{t-1}[e_{it} \mid S_{i,t-1}] = 0 \qquad (17)$$

where the (unconditional) mathematical expectation E denotes expectations taken over the realizations of the stochastic variables. Note that the population moment condition $E[S_{i,t-1}\, e_{it}]$ requires the forecast error e_{it} be orthogonal to all elements of the information set, including the information contained in previous forecast errors. For $s \geq 1$, this implies $E[e_{i,t-s}\, e_{it}] = 0$ so that the forecast errors will be serially uncorrelated.[9]

Provided the distribution of the disturbance $\{A_{it} : t = 1, 2 \ldots T\}$ is a stationary stochastic process, the random variable $(S_{i,t-1,j}\, e_{it})$ for $j = 1, 2, \ldots P$ will satisfy:[10]

$$E(S_{i,t-1,j}\, e_{it}) = \operatorname*{plim}_{T \to \infty} \frac{1}{T} \sum_{t=2}^{T} S_{i,t-1,j} \cdot e_{it} = 0 \qquad \text{for} j = 1, 2 \ldots P$$

[9]Although this result will hold for the model considered in this chapter, it is not a general result. As noted by Hansen & Singleton (1982) and Hotz et al. (1988), this result holds in the present application because the information set contains all of variables used in (15) or (16) and all previous periods.

[10]See Lahiri (1993) or Hamilton (1993)

Define the vector function:

$$f(X_{it}, \Phi_0) = S_{i,t-1}\, h(W_{it}, \Phi_0) = S_{i,t-1}\, e_{it}$$

where X_{it} is the matrix $[W_{it}, S_{i,t-1}]$. The (population) moment conditions (17) imply a $P \times 1$ vector function $E[f(X_{it}, \Phi_0)] = 0$.

The idea behind the Generalized Method of Moments (GMM) estimator is to choose the $K \times 1$ parameter vector Φ in order to make $g(X_i, \Phi)$ as close as possible to the population moment condition $E[f(X_{it}, \Phi_0)] = 0$ where:

$$g(X_i, \Phi) = \frac{1}{T} \sum_{t=2}^{T} f(X_i, \Phi) = \frac{1}{T} \sum_{t=2}^{T} S_{i,t-1}\, h(W_{it}, \Phi)$$

For the case where $P > K$, the GMM estimator $\hat{\Phi}$ is the value of Φ that minimizes the scalar:

$$Q(X_i, \Phi) = [g(X_i, \Phi)]'\; B_i\; [g(X_i, \Phi)] \tag{18}$$

where B_i is a $P \times P$ positive definite weighting matrix.[11]

Suppose there exists T periods of data for a random sample of N production plants. Since the parameter vector Φ_0 is assumed to be identical for each i, it is possible to pool the observations. In this case the GMM estimator $\hat{\Phi}$ is the value of Φ that minimizes the scalar:

$$Q(X, \Phi) = [g(X, \Phi)]'\; \mathbf{B}\; [g(X, \Phi)] \tag{19}$$

where $\mathbf{B}$ is a $P \times P$ stochastic positive definite weighting matrix and

$$g(X, \Phi) = \frac{1}{N} \sum_{i=1}^{N} g(X_i, \Phi) = \frac{1}{N} \sum_{i=1}^{N} \frac{1}{T} \sum_{t=2}^{T} S_{i,t-1}\, h(W_{it}, \Phi) \tag{20}$$

This estimation strategy is based on a strong assumption concerning the dependence of forecast errors across production units at a point in time. Estimators

[11]Hansen (1982) and Hansen & Singleton (1982) show that setting $\mathbf{B}$ equal to the inverse of the asymptotic covariance matrix of the sample mean of $f(X_{it}, \Phi_0)$, is optimal in the sense that it yields estimates $\hat{\Phi}$ with the smallest asymptotic variance.

formed by using the sample orthogonality conditions $g(X_i, \Phi)$ will yield consistent estimates of the parameter vector if, when averaged over production units, they converge to zero as N gets large. As shown by Chamberlain (1984), the hypothesis of rational expectations implies the sample average of $(S_{i,t-1}\, e_{it})$ should converge to zero as $T \to \infty$ (for a given N) but not necessarily as $N \to \infty$ (for a given T). This becomes especially important when there are common components to the forecast errors. In this case the forecast errors might be correlated across production units so that the cross sectional mean forecast error need not be zero. However, when these aggregate shocks have a mean of zero and are serially uncorrelated, it might be expected that the effects of these aggregate shocks "average out" over time, provided the time dimension of the panel is sufficiently large. Relative to existing panel data sets, which generally have short time dimensions, the data used in this chapter cover twenty five years. Consequently, it seems reasonable to assume that the effects of any aggregate shocks are indeed averaged out and the estimator formed by using the sample orthogonality conditions $g(X_i, \Phi)$ will yield consistent estimates of the parameter vector.

4.4.1 Some Specification Tests

The population moment conditions are derived from the underlying microeconomic model of organizational capital and the assumption of rational expectations. These assumptions may or may not be consistent with the data. It is possible to decompose the P population moment conditions into *identifying* restrictions and *over-identifying* restrictions. There are K identifying restrictions that are used in parameter estimation and $(P - K)$ over-identifying restrictions. In the sample, the analog to the identifying restrictions are satisfied for the estimator $\hat{\Phi}$ so it is not possible to test whether the identifying restrictions hold at the true parameter vector Φ_0. However, the over-identifying restrictions are not imposed during estimation so that it is possible to test whether these restrictions hold for the population. Hansen (1982) proposed the following test of whether the null hypothesis $E[f(X_{it}, \Phi_0)] = 0$ is consistent with the data:

$$J = NT \cdot Q(X, \hat{\Phi}) = NT \cdot \left[g(X, \hat{\Phi}\right]' \mathbf{B} \left[g(X, \hat{\Phi}\right] \tag{21}$$

which is distributed (asymptotically) as χ^2 with $(P-K)$ degrees of freedom. This J-test will be a joint test of the moment restrictions and the structural model itself, including the hypothesis of rational expectations.

It is often the case that the J-test of the over-identifying restrictions rejects the null hypothesis that all P moments are correct. Rejection of this null hypothesis indicates that not all of these P moment conditions are valid. Andrews (1999) proposed a moment selection procedure that estimates which moments are correct and which are incorrect. This moment selection procedure is based upon the value for the J-test and includes a bonus term that rewards the use of more moment conditions.[12] The intuition for this bonus term can be seen by studying the just-identified case where the population moments $E[f(X_{it},\Phi_0)]=0$ represent K equations in K unknowns which are solved by Φ_0. In the sample, the moments conditions $g(X,\Phi)=0$ will be satisfied for the estimator $\hat{\Phi}$. In the over-identified case, it is not possible to find a $\hat{\Phi}$ that satisfies $g(X,\hat{\Phi})=0$ exactly. Instead, the GMM estimator $\hat{\Phi}$ is chosen so that $g(X,\hat{\Phi})$ is close to zero. As the number of over-identifying restrictions increases, the value of the sample moments $g(X,\Phi)$, evaluated at $\hat{\Phi}$, must diverge from zero. Consequently, the value of the J-test statistic will be increasing in the number of over-identifying restrictions so that selecting moment conditions by minimizing the value of J-test statistic will likely result in the selection of too few valid moments.[13] The bonus term represents a correction to offset this increase in the value of the J-test statistic when moment conditions are added, even if they are correct moment conditions.

[12]As noted by Andrews (1999), these moment selection criteria are GMM analogues of the widely used model selection criteria which penalize the inclusion of additional explanatory variables.

[13]Obviously, the extent to which the J-test statistic increases will depend upon whether the additional moment conditions are valid in the sample. Fundamentally, the inclusion of invalid moment conditions must increase the J-test value more than the inclusion of valid moment conditions. Although, the value of the J-test statistic will be increasing in the number of over-identifying restrictions, the inclusion of additional valid moment conditions can never increase the asymptotic efficiency of the estimator.

4.5 Data

The structural model provides the following $P \times 1$ vector of sample moment conditions:

$$g(X_i, \Phi) = \frac{1}{T} \sum_{t=2}^{T} S_{i,t-1}\, h(W_{it}, \Phi) \tag{22}$$

where $S_{i,t-1}$ denotes the information set at time $t-1$ that is observed by the econometrician and

$$h(W_{it}, \Phi) = \frac{\phi}{\mu} \frac{v_{i,t-1} Q_{i,t-1}}{P_{t-1} s_{t-1} M^*_{i,t-1}} + \beta \left[\varepsilon (1-\eta) + \eta\right] \frac{P_t w_t H^*_{it}}{P_{t-1} w_{t-1} H^*_{i,t-1}}$$

$$- \beta \eta \frac{\phi}{\mu} \frac{v_{it} Q_{it}}{P_{t-1} s_{t-1} M^*_{i,t-1}} - 1 \tag{23}$$

where the restriction of constant returns to scale in the accumulation technology ($\gamma = 1 - \eta$) has been imposed.[14]

The Annual Survey of Manufactures contains data on the variables needed to estimate the parameters of the dynamic equation (23). The Annual Survey of Manufactures (ASM) is a lengthy panel of annual observations for a large cross section of the population of Canadian manufacturing establishments over the period 1973-1997. An establishment is defined by Statistics Canada as the smallest unit capable of reporting certain specified input and output data.[15] Each establishment is identified by a unique identifier that changes if and only if the name of the establishment changes and the establishment is physically relocated and there is a change in ownership. The target population of the survey is all establishments primarily engaged in manufacturing with employees and with a value of shipments over $\$30,000$. The survey uses two methods of data collection—direct and administrative. The direct survey method covers approximately 60% of manufacturing establishments. The long form is sent

[14]Recall that both (15) and (16) are equivalent expressions of the first order condition arising from the maximization problem of individual production units. It is anticipated that the cost of intermediate inputs is measured more precisely than the wage bill. In particular, the wage bill may have a utilization component. For this reason (23) is used as the estimating equation.

[15]This includes materials and supplies used, goods purchased for resale, fuel and power consumed, number of employees and salaries and wages, man hours worked and paid, inventories and shipments or sales.

to large establishments and is highly detailed. This long form covers establishments that account for approximately 90% of total manufacturing shipments. Unlike the long form, the short form does not collect information on raw materials or separate administrative employees from production workers. The records for the remaining 40% of establishments are extracted from administrative files.

For the purposes of the present study, the sample was restricted to establishments classified as plants that are present in the survey for all years from 1973 to 1997 and report using the long form at least once over the period 1973 to 1997. This produces a balanced panel of annual observations for 6139 plants. It excludes establishments classified as sales offices, warehouses or head offices. This focus upon continuing plants does not suggest that entry and exit are unimportant. Baldwin & Gu (2002) report that 39% of the plants present in 1979 represent new plants that entered over the period 1973-1979, 57% of the plants present in 1988 represent new plants that entered between 1979-1988, and 39% of the plants present in 1997 represent new plants that entered between 1988-1997. In addition, some 29% of plants present in 1973 were no longer operating in 1979, 47% of plants present in 1979 were no longer operating in 1988, and 47% of plants present in 1988 were no longer operating in 1997. Despite this, the focus upon continuing plants might be motivated in several ways.

Firstly, the previous two chapters have studied the accumulation of organizational capital in a macroeconomic context in which there is no entry or exit. Consequently, the decision to restrict the sample to a balanced panel of continuing plants reflects this assumption.

Secondly, the structural model presented in this thesis is essentially a model of plant or (establishment) behaviour, reflecting the level at which data is collected in the Annual Survey of Manufactures. However, the decision to exit will likely be (endogenously) determined at the firm level which requires a well specified structural model that explicitly accounts for the decision to exit. Although the determinants of entry and exit in the presence of organizational capital accumulation might be an important research question, such a structural model will generally be outside the scope of this thesis. This is further complicated by data considerations and especially the ability to aggregate the plant level observations in the data to obtain firm level variables. Since the data cover 25 years, this requires considerable specific knowledge regarding corporate restructuring, mergers, and acquisitions. Olley & Pakes (1996) discuss some potential selection biases that may be introduced by restricting the sample to continuing plants.

4.6 Results

The sample moments, defined by (22) and (23), may be written in the following simplified form:

$$h(W_{it}, \Phi) = \frac{\phi}{\mu} RATIO1 + \beta\left[\varepsilon\left(1-\eta\right)+\eta\right] RATIO2 - \beta\,\eta\,\frac{\phi}{\mu} RATIO3 - 1$$

where

$$RATIO1 = \frac{v_{i,t-1}Q_{i,t-1}}{P_{t-1}s_{t-1}M_{i,t-1}}$$

$$RATIO2 = \frac{P_t w_t H_{it}}{P_{t-1}w_{t-1}H_{i,t-1}}$$

$$RATIO3 = \frac{v_{it}Q_{it}}{P_{t-1}s_{t-1}M_{i.t-1}}$$

where the cost minimizing input bundles have been replaced by their corresponding values in the data.

The quotients RATIO1 and RATIO3 may be calculated using either the value of production or the value of shipments. The difference between these two measures of output reflects an adjustment for the change in inventories. The value of shipments data measure the net selling value of goods produced by the manufacturing plants and excludes discounts, returns and allowances, sales tax, excise taxes and duties and charges for outward transportation. Since there is no considerable difference in the results using the value of manufacturing shipments, the results presented in this chapter relate to the value of production.

Results may be shown separately for RATIO1 and RATIO3 calculated using the value of output attributed to manufacturing activity (VPM) and total activity (VPT). The structural model presented above implies that plants optimally choose total output rather than manufacturing output. In addition, the relative merits of each measure are driven by data considerations. Not all data can be decomposed into manufacturing activity and total activity. The activity for all small establishments is classified as manufacturing activity. In addition, labour data are shown separately for manufacturing activity only in the case of production workers so that the number of salaried employees includes non-production workers involved in both manufacturing and non-manufacturing activity. The cost of heat and power cannot be shown separately for non-manufacturing activity. For these reasons, the results presented in this paper relate to total production (VPT) only.

The cost of intermediate inputs ($P_t s_t M_{it}$) is constructed as the sum of heat and power costs and the cost of production materials. No adjustment is made for the change in the inventory of raw materials. The total wage bill ($P_t w_t H_{it}$) includes the gross earnings of both salaried and non-salaried (production) workers before deductions for income tax. It includes payments for overtime and paid leave as well as bonuses and commissions paid. Remuneration to outside pieceworkers is included in the cost of materials.

The assumption of rational expectations implies that candidates for the instruments S_{it} include any variables in the establishment's information set $\Omega_{i,t-1}$ at time $t-1$, including lagged values of the endogenous variables. Since the dataset does not contain many exogenous variables that might be used as instruments, only subsets of six (6) possible instruments have been used to apply the moment selection procedures of Andrews (1999).[16] These instrument sets include single lags of RATIO1, RATIO2, RATIO2_M, RATIO3, RATIO_4, and a constant. The instruments RATIO1, RATIO2, and RATIO3 are defined above and:

$$RATIO2\_M = \frac{P_t s_t M_{it}}{P_{t-1} s_{t-1} M_{i,t-1}} \qquad \text{and} \qquad RATIO4 = \frac{v_{it} Q_{it}}{v_{i,t-1} Q_{i,t-1}}$$

The (optimal) instrument set, as a subset of these six instruments, is chosen by

[16]The simulation evidence suggests that the relative performance of the GMM estimator in finite samples is improved for small instrument sets. Podivinsky (1999) reviews this simulation evidence.

minimizing the GMM_BIC, GMM_HQIC and GMM_AIC moment selection criteria of Andrews (1999).[17] Results are presented for each 2-digit industrial sector using the (Canadian) Standard Industrial Classification and a more aggregated group based upon a classification according to Baldwin & Raffiquzzaman (1994).[18] This OECD classification divides the sample into five (5) industry groups. Appendix A.4 presents some characteristics of these broad industry groups. These five broad industry groups are formed using 4-digit industry classifications rather than 2-digit codes so that it is difficult to characterize these groups according to 2-digit industrial sectors. However, Appendix A.4 also provides a crude characterization of these OECD groups in terms of 2-digit industrial sectors.

Using the Cobb-Douglas cost function (8) which provides constant input shares in total cost, the input shares in total revenue may be expressed as:

$$\frac{P_t w_t H_{it}}{v_{it} Q_{it}} = \alpha \frac{MC_{it}}{v_{it}} \qquad \text{and} \qquad \frac{P_t s_t M_{it}}{v_{it} Q_{it}} = \phi \frac{MC_{it}}{v_{it}}$$

In the absence of the accumulation of organizational capital as a productivity enhancing factor of production, the demand system implies a constant markup of (output) price over marginal cost MC_{it} given by μ. However, the structural model with monopolistic competition and organizational capital implies that establishments recognize that raising prices today will result in lower current output which lowers the quantity of organizational capital available next period which raises future costs and lowers future profits. Consequently, the structural model implies the optimal output price will be described by a dynamic equation. Although, the organization will generally select a lower output price in the presence of organizational capital accumulation, marginal cost will also be a decreasing function of the stock of organizational capital, for a given level of output Q_{it}. Therefore, the markup over marginal cost will not be constant and the parameter ϕ/μ can no longer be interpreted as the share of intermediate inputs in output. Despite this, the parameter ϕ/μ will likely be related to the mean output share of intermediate inputs for each industry group which is used

[17]Following Andrews (1999) these tests are performed using an optimal weighting matrix constructed using the "de-meaned" sample moment conditions.

[18]Starting in 1998, the ASM classifies establishments according to the North American Industry Classification System (NAICS).

as an initial value for ϕ/μ in the GMM algorithm. The starting values for the other parameters are set at $\eta_0 = 0.5$ and $\varepsilon_0 = 0.5$. The results are not particularly sensitive to these initial values for η and ε.

Tables 4.1 and 4.2 present some summary statistics for the labour share and intermediate inputs share in the value of output. It is clear that the mean labour share in revenues is considerably lower than the calibrated value used in Chapters 2 and 3. This is because, relative to (8), the Cobb-Douglas production technology used in Chapters 2 and 3 is essentially a value-added production technology so that the labour share in these chapters reflects the share of labour in value-added revenues.

Note that the standard model of monopolistic competition is nested within the structural model of plant behaviour. In the case that organizational capital has no effect upon productivity ($\varepsilon = 0$) and there is no accumulation of organizational capital ($\eta = 0$), the estimating equation (23) collapses to the familiar condition that the share of intermediate inputs in the value of output will be constant and equal to ϕ/μ where μ is the constant markup over marginal cost. Consequently, if the accumulation of organizational capital were relatively unimportant, the estimate of ϕ/μ obtained from estimating (23) should not be significantly different from the mean share of intermediate inputs in the value of output observed in the data. Although this is an approximate test of the dynamic structure of the theoretical model, it does provide some information regarding the importance of the accumulation of organizational capital.[19]

The accumulation technology (10) implies a log-linear law of motion for organizational capital. Combined with the restriction of constant returns to scale $(\eta+\gamma) = 1$, there are two important limiting cases for this accumulation technology. Consider the case where $\eta = 1$ which imposes $\gamma = 0$. This implies there is no accumulation of organizational capital from past output. The (log) stock of organizational capital is composed entirely of the initial endowment of organizational capital. Similarly when $\eta = 0$ which imposes $\gamma = 1$, the stock of organizational capital will be determined by current output so that only the most recent production experience matters:

Since these limiting cases have important implications for the behaviour of

[19]This test treats the mean share of intermediate inputs as known constant. In principle, this mean share should be treated as a random variable.

organizations, it is useful to test whether these restrictions are consistent with the data. Recall from the general equilibrium model of Chapter 2, that a steady state z/y will not be well defined for $\eta = 1$.

Tables 4.3 and 4.4 present some estimation results for the five OECD industrial groups. Tables 4.5 and 4.6 present estimation results for each of the 2-digit industrial groups. Each industry group is estimated separately so that no cross equation restrictions have been imposed. There is some variation in the instrument sets selected by the Andrews (1999) moment selection procedures.[20] Although the three moment selection procedures select the same instrument set for all of the OECD groups, the GMM_AIC selects a different instrument for the entire sample. This problem becomes more important at the 2-digit industry level. The GMM_AIC selects a different instrument set for 7 of the 18 industry groups. Although the results have been calculated using all three moment selection procedures, the results for the GMM_HQIC will not be presented because they are so similar to the results for the GMM_BIC.[21]

An examination of Tables 4.3 to 4.6 reveal that the J-test of the over-identifying restrictions is not rejected at the 5% level for any of the industry groups using the GMM_AIC. Using the GMM_BIC it is not rejected at the 1% level for any of the industry groups. At the 5% level, it is rejected for Furniture & Fixtures and Electrical industries. Since this J-test of the over-identifying restrictions will be a joint test of the moment restrictions and the structural model itself, including the functional forms, these result imply that the accumulation of organizational capital and the corresponding dynamic structure is supported by the data. Moreover, the results imply that the specific functional forms cannot be rejected by the data and that the errors are uncorrelated with the instruments. This result is particularly important given the evidence on the small sample properties of the GMM estimator. Podivinsky (1999) reviews both the theoretical literature and the simulation evidence on the finite sample distribution of the GMM estimator. There is somewhat of a consensus that this finite sample distribution may be a poor approximation to the asymptotic

[20]This is not surprising since the GMM_AIC involves a bonus term that is not a function of the sample size. The GMM_AIC will not be consistent. As noted by Andrews (1999, p.553), the GMM_AIC has a positive probability, even asymptotically, of selecting too few moments.

[21]With the exception of two of the 2-digit industry groups (Electrical and Chemicals), the GMM_BIC and GMM_HQIC select the same instrument set.

distribution of the estimator and in particular that the J-test of the over-identifying restrictions tends to reject the null too frequently, relative to its asymptotic size. In light of this evidence, the J-test statistics reported in Tables 4.3 to 4.6 are particularly impressive.

The final rows of Tables 4.3 to 4.4 provide parameter estimates for the entire sample.[22] Note that the estimates of the parameter ε should be interpreted as the organizational capital elasticity of output.[23] Using both the GMM_AIC and GMM_BIC, the estimate of ε is not significantly different from zero at the 5% level.[24]

The estimate of η which captures the contribution of the past stock of organizational capital to the stock of organizational capital is significantly different from zero at the 5% level, for both the GMM_AIC and GMM_BIC. The estimate of η is also significantly different from one, at the 5% level. Of course, this two-sided test does not rule out the possibility that $\eta > 1$ or $\eta < 0$. Using a one-sided test, the hypothesis that $\eta \leq 0$ is not supported by the data. Similarly, the hypothesis that $\eta \leq 1$ is supported by the data. These results suggest that the limiting cases in which the stock of organizational capital is determined entirely by the initial endowment or determined entirely by current output are not consistent with the data.

Using a t-test, the estimate of ϕ/μ is significantly different from zero and also significantly different from one. In addition, the hypothesis that $\phi/\mu \leq 0$ is not supported by the data. However, the hypothesis that $\phi/\mu \leq 1$ is supported by the data. The estimate of ϕ/μ is significantly different from the mean share of intermediate inputs in the value of output, at the 5% level, using both the GMM_AIC and GMM_BIC. Alternatively, the 95% confidence interval constructed around the estimate of ϕ/μ does not overlap the 95% confidence interval constructed around the sample mean of the share in output. This result, in conjunction with the value of the J-test statistic, implies that the dynamic structure associated with the accumulation

[22] The simulation evidence presented in Podivinsky (1999) suggests that caution should be exercised when conducting statistical inference and hypothesis testing using the GMM estimator in finite samples. This might become particularly important for the results for certain 2-digit industry groups.

[23] For example, all else equal, a one percentage point increase in the stock of organizational capital will raise output by ε%.

[24] When the true value of ε is zero, the organization will still accumulate organizational capital since it is unavoidable. However, this organizational capital does not improve productivity so that the level of output is determined independently of the stock of organizational capital.

of organizational capital might be consistent with the data.

These results for the full sample of continuing manufacturing plants are not considerably different from the results obtained by Johri & Letendre (2002) for the aggregate U.S. economy.[25] This is primarily because the standard errors associated with the estimates of the organizational capital parameters, presented in Tables 4.3 and 4.4, are quite large. Using a t-test, the estimates of ε, using both the GMM_AIC and the GMM_BIC are not significantly different from the estimate of $\varepsilon = 0.23925$ obtained by Johri & Letendre (2002). At the 5% level, the estimate of η using the GMM_BIC is not significantly different from the estimate of $\eta = 0.94952$ obtained by Johri & Letendre (2002). For the GMM_AIC, the null hypothesis that the estimate of η is not significantly different from the estimate of $\eta = 0.94952$ is not rejected at the 1% level.

Care must be exercised in comparing the results presented in Tables 4.3 and 4.4 to the aggregate results of Johri & Letendre (2002). In contrast to Johri & Letendre (2002), the structural model presented and estimated in this chapter is a partial equilibrium model of plant behaviour. Despite this, the general equilibrium model of Johri & Letendre (2002) involves a central planner maximizing the utility of a representative agent whose preferences take the indivisible labour specification used in Chapters 2 and 3. As noted in Chapter 3, this implies that the demand side of the labour market will determine the optimal quantity of employment. Consequently, it is expected that the estimates from the partial equilibrium model presented in this chapter will not be considerably different than those of Johri & Letendre (2002). Of course, the critical difference is that the results presented in Johri & Letendre (2002) are based upon aggregate data for the U.S. economy whereas the estimation results presented in this chapter relate to Canadian manufacturing only and exclude the services sector.

The remainder of Tables 4.3 and 4.4 provide estimates for the five OECD industry groups. The estimate of ε is significantly different from zero for two of these groups–Labour Intensive and Scale Based. For these two industries, the hypothesis

[25] In contrast to this chapter, Johri & Letendre (2002) impose constant returns to scale in the production technology. Cooper & Johri (2002) present results, imposing constant returns to physical capital and labour, based upon production function estimation. Unfortunately, the standard errors associated with their estimates ε and η are quite high.

$\varepsilon \leq 0$ is not supported by the data. The estimate of η is significantly different from zero for all of the five OECD groups and using a one-sided test the hypothesis $\eta \leq 0$ is not supported by the data. The estimate of η is significantly different from one for all OECED groups with the exception of Scale Based Industries. For these four industries, the hypothesis that $\eta \leq 1$ is supported by the data. These results suggests that the limiting cases in which the stock of organizational capital is determined entirely by the initial endowment or determined entirely by current output are not consistent with the data.

Using a one-sided t-test, the estimate of ϕ/μ is significantly different from zero for Natural Resource Industries; Labour Intensive Industries and Product Differentiated Industries. For these industries, the hypothesis that $\phi/\mu \leq 0$ is not supported by the data. The estimate of ϕ/μ is also significantly different from one for all OECD industries with the exception of Natural Resource Industries. Similarly, for these industries, the hypothesis that $\phi/\mu \leq 1$ is supported by the data. For all OECD industries, the estimate of ϕ/μ is significantly different from the mean share of intermediate inputs in the value of output, at the 5% level. Alternatively, the 95% confidence interval constructed around the estimate of ϕ/μ does not overlap the 95% confidence interval constructed around the sample mean of the share in output. This result, in conjunction with the value of the J-test statistic, implies that the dynamic structure associated with the accumulation of organizational capital might be consistent with the data, for all of these five broad industry groups.

The point estimates for ε and η for the five OECD groups are not considerably different from the results obtained by Johri & Letendre (2002). Using a simple t-test, the estimates of ε, for all OECD groups are not significantly different from the estimate of $\varepsilon = 0.23925$ obtained by Johri & Letendre (2002). Similarly, at the 1% level, the estimates of η for all industry groups are not significantly different from the estimate of $\eta = 0.94952$ obtained by Johri & Letendre (2002).[26]

A comparison of the results presented in Tables 4.3 and 4.4 for the full sample of continuing Canadian manufacturing plants to the results for the five OECD groups indicates some degree of heterogeneity in the point estimates at the less ag-

[26]At the 5% level, the estimates of η for Labour Intensive and Scale Based Industries are significantly different from the estimate obtained by Johri & Letendre (2002).

gregated level. However, the point estimates for these OECD groups are generally not significantly different from those for the full sample.

In order to put these estimates of ε and η in some perspective it is useful to consider the following experiment. Consider an increase in the current stock of organizational capital Z_{it} by a factor λ. When there are constant returns to scale in physical capital, labour, and intermediate inputs so that $\alpha+\theta+\phi=1$, the percentage reduction in current unit costs of production will be given by $(1+\lambda)^{-\varepsilon}-1$. For $\lambda=2$, this would correspond (approximately) to the learning rate in traditional studies of learning-by-doing.[27] The estimates of $\varepsilon=0.2506$ and $\varepsilon=0.7856$ for the full sample in Tables 4.3 and 4.4 would imply a learning rate of 15.94% and 41.99% respectively.

Tables 4.5 and 4.6 present some estimates for the 2-digit industry groups. Consider the results in Table 4.5 based upon the GMM_AIC moment selection criteria. For 7 of the 2-digit industry groups, the estimate of ε is significantly different from zero. These estimates range from $\varepsilon=0.3059$ for Wood Industries to an implausibly large value of $\varepsilon=0.9788$ for Machinery. For these industries, the hypothesis $\varepsilon\leq 0$ is not supported by the data.

For 10 of the 18 industry groups the estimates of η are significantly different from zero and for these industries the hypothesis $\eta\leq 0$ is not supported by the data. The estimate of η is also significantly different from one for only 6 industry groups. These six industry groups are a subset of the 10 industry groups that have an estimate of η significantly different from zero.

With the exception of Food & Beverages and Petroleum & Coal, the estimates for ϕ/μ are significantly different from the mean share of intermediate inputs at both the 5%. Once again, in conjunction with the J-test, these results provide some limited evidence that the dynamic structure associated with the accumulation of organizational capital might be consistent with the data.

Table 4.6 presents results using the GMM_BIC moment selection procedure. There are 4 industries for which the estimate of ε is significantly different from zero—Rubber & Plastic, Textiles, Wood, and Machinery. With the exception of Wood industries, these are industries for which all of the three moment selection procedures

[27]Since there is organizational forgetting, the accumulation equation implies that a 100% increase in the stock of organizational capital would require more than a 100% increase in cumulative output

select the same instrument set. For these industries, the hypothesis $\varepsilon \leq 0$ is not supported by the data.

For 14 of the 18 industry groups the estimates of η are significantly different from zero and for these industries the hypothesis $\eta \leq 0$ is not supported by the data. The estimate of η is also significantly different from one for only 8 industry groups. These eight industry groups are a subset of the 14 industry groups that have an estimate of η significantly different from zero.

With the exception of Food & Beverages, Petroleum & Coal, and Chemicals the estimates for ϕ/μ are significantly different from the mean share of intermediate inputs at both the 5%. Once again, in conjunction with the J-test, these results provide some limited evidence that the dynamic structure associated with the accumulation of organizational capital might be consistent with the data.

Similar to the results for the GMM_AIC, an examination of Table 4.6 indicates some puzzling results for Furniture & Fixtures and Transport. Despite the J-test of the over-identifying restrictions suggesting that the dynamic structure of the model is not rejected by the data, none of the point estimates are significantly different from zero.

Interestingly, the estimates for the organizational capital parameters presented in Tables 4.5 are not considerably different from either the estimates for the full sample or the estimates obtained by Johri & Letendre (2002). This is primarily because some of the estimates of the structural parameters are estimated with relatively large standard errors. With the exception of Furniture & Fixtures, Machinery, and Chemicals, a simple t-test suggests that the estimates of ε, are not significantly different from the estimate of $\varepsilon = 0.23925$ obtained by Johri & Letendre (2002). At the 1% level, only the estimate of ε for Chemicals is significantly different from $\varepsilon = 0.23925$. These results also hold for the value of $\varepsilon = 0.2506$ obtained for the full sample of manufacturing plants. Similarly, at the 1%, only the estimate of η for Wood industries is significantly different from the estimate of Johri & Letendre (2002). With the exception of Food & Beverages, the estimates of η are not significantly different from those obtained for the full sample.

Consider the results presented in Table 4.6 using the GMM_BIC. At the 1% level, a simple t-test suggests that the estimates of ε, are not significantly different from the estimate of $\varepsilon = 0.23925$ obtained by Johri & Letendre (2002), for any of the 2-digit industry groups. However, at the 1% level, the estimate of ε for Rubber, Wood, and Fabricated Metals is significantly different from $\varepsilon = 0.7856$ obtained for the full sample. Similarly, at the 1% level, only the estimate of η for Wood and for Fabricated Metals is significantly different from the estimate obtained by both Johri & Letendre (2002) and the estimate obtained for the full sample.

4.7 Discussion and Conclusions

The results in Tables 4.3 and 4.4 and in Tables 4.5 and 4.6 reveal the existence of considerable heterogeneity in the point estimates associated with the organizational capital parameters across both the broad OECD industry groups and the more disaggregated 2-digit industry groups. A robust finding from existing studies is that plant level productivity distributions are typically characterized by considerable heterogeneity both between and within narrowly defined industry classifications. The relatively large standard errors associated with estimates of the structural parameters provided in this chapter probably reflect this considerable plant level heterogeneity.

For the more disaggregated results, the structural parameters are estimated with considerable error. This indicates that within industry heterogeneity is most likely an important consideration. In particular, the existence of within industry heterogeneity might be consistent with a value for the J-test that supports the dynamic structure of the model in conjunction with insignificant point estimates for several of the industry groups. It is possible that, for several industry groups, this plant level heterogeneity dominates any learning effects that might be identified from the plant level data. Despite this, the point estimates for several of the 2-digit industrial sectors (for example Wood Industries) are estimated relatively precisely.

These relatively large standard errors make it difficult to evaluate these estimates in terms of the established sources of bias associated with estimates of learning effects using production functions. Proceeding with due caution, the results presented in Tables 4.3 and 4.4 and in Tables 4.5 and 4.6 reveal that the J-test of the over-identifying restrictions is not rejected at the 5% level for any of the industry groups using the GMM_AIC moment selection procedure. Using the GMM_BIC, it is rejected for Furniture & Fixtures and Electrical industries only. These results suggest that the dynamic structure implied by a structural model that allows for the accumulation of organizational capital accumulation cannot be rejected by the data. This implies that the accumulation of organizational capital might be important consideration for the productivity of continuing manufacturing establishments. This is a particularly noteworthy result given that the J-test of the over-identifying restrictions tends to reject the null too frequently in finite samples.

Consequently, existing studies of learning-by-doing that aim to quantify the productivity of (accumulated) production experience without also considering the (endogenous) accumulation of this production experience are likely to be seriously flawed. Importantly, these studies which ignore the interaction between market structure and the accumulation of organizational capital are missing an important dynamic component to plant behaviour.

One disadvantage of existing studies of learning-by-doing has been their restriction to specific industries or organizations primarily dictated by the need to construct measures of production experience since birth. In contrast, this chapter has detailed a method for estimating the contribution of organizational capital to plant level productivity using available plant level census data. Since the estimation does not require data on the stock of organizational capital, the estimation method considerably reduces the data requirements since there is no need to track production units from their birth. Consequently, this chapter uses a lengthy panel of annual observations for a large cross section of manufacturing establishments. This provides a bridge between the microeconomic evidence for learning-by-doing in specific industries and organizations and the aggregate results of Cooper & Johri (2002) and Johri & Letendre (2002) while at the same time using data collected at the plant level. Importantly, this chapter presents some estimates of the organizational capital parameters across a diverse range of manufacturing industries. Having established the existence of considerable industry level variation in the estimates of the organizational capital parameters, future research will need to explore the particular characteristics of these industries associated with variations in these estimates.

This industry variation in the point estimates for the structural parameters associated with the accumulation of organizational capital indicates that estimates of these parameters based upon more aggregated data might produce misleading results.

Despite this, the large standard errors associated with these point estimates imply that the industry level estimates, for the organizational capital parameters, presented in this chapter, are not considerably different from either those obtained by Johri & Letendre (2002) for the aggregate U.S. economy or the estimates obtained for the full sample of manufacturing establishments. Proceeding with due caution, this is an important result since it implies that the plant level observations support the evidence using more aggregated data.

The previous two chapters have detailed some implications for the aggregate economy arising from the accumulation of organizational capital by production units. It has been shown that the accumulation of organizational capital (by production units) introduces an important dynamic structure into the choice problem of production units that is capable of generating an internal propagation mechanism, beyond that associated with physical capital accumulation. The results presented in this chapter provide a microeconomic foundation for this dynamic structure. Importantly these results suggest that the internal propagation mechanism associated with the accumulation of organizational capital at the aggregate level, is supported by the plant level evidence.

OECD	NT	LSHARE[a]	MSHARE[b]
Natural Resources	51382	0.2053	0.5993
		(0.1492)	(0.2020)
Labour Intensive	34459	0.2992	0.5092
		(0.1682)	(0.2048)
Scale Based	40265	0.2772	0.5048
		(0.1445)	(0.1964)
Product Differentiated	17803	0.3174	0.4591
		(0.1590)	(0.1713)
Science Based	9566	0.2446	0.5092
		(0.1558)	(0.2976)
Full Sample	153475	0.2607	0.5324
		(0.1598)	(0.2112)

[a] LSHARE denotes labour share in revenues
[b] MSHARE denotes share of intermediate inputs in Revenues

Table 4.1: Means and Standard Deviations: OECD Industry Groups

SIC802	NT	LSHARE[a]	MSHARE[b]
Food & Beverages	23749	0.1529	0.6766
		(0.1558)	(0.2118)
Rubber & Plastic	5894	0.2408	0.5370
		(0.1073)	(0.1450)
Leather	1198	0.2972	0.5119
		(0.1141)	(0.1296)
Textiles	5148	0.2631	0.5443
		(0.1616)	(0.1660)
Clothing	7637	0.3204	0.4961
		(0.1908)	(0.2654)
Wood & Lumber	13095	0.2606	0.5668
		(0.1363)	(0.1931)
Furniture & Fixtures	4421	0.3051	0.4968
		(0.1564)	(0.1379)
Paper	6990	0.2115	0.5808
		(0.0809)	(0.1267)
Printing & Publishing	15174	0.3690	0.3883
		(0.1222)	(0.1569)
Primary Metals	4314	0.2476	0.5395
		(0.1344)	(0.1910)
Fabricated Metals	19997	0.3200	0.4743
		(0.1522)	(0.1828)
Machinery	7186	0.2810	0.4983
		(0.1155)	(0.1526)
Transportation	6364	0.2788	0.5254
		(0.1412)	(0.1799)
Electrical	5377	0.2553	0.5231
		(0.1638)	(0.3420)
Non–Metallic Minerals	8880	0.2291	0.5239
		(0.1056)	(0.1534)
Refined Petroleum & Coal	1081	0.0745	0.7625
		(0.0737)	(0.1774)
Chemicals	8824	0.1546	0.5741
		(0.1001)	(0.1933)
Instruments	7921	0.3558	0.4418
		(0.1989)	(0.2284)

[a,b] See the notes attached to Table 4.1

Table 4.2: Means and Standard Deviations: 2-digit Industry Groups

OECD	ϕ/μ	ε	η	J[a]	overid[b]
Nat. Resources	**1.1863**[c]	-0.1927	**0.9141**	0.1325	2[d]
	(0.2596)[d]	(0.3326)	(0.0292)	(0.9359)	
Lab. Intensive	**0.0447**	**0.4240**	**0.8548**	1.2540	2
	(0.0199)	(0.1685)	(0.0458)	(0.5342)	
Scale Based	0.0472	**0.5637**	**0.7955**	1.5568	2
	(0.0287)	(0.2311)	(0.1162)	(0.4591)	
Prod. Diff.	**0.1396**	0.2573	**0.8365**	0.1421	2
	(0.0495)	(0.1526)	(0.0534)	(0.9314)	
Science Based	0.1525	0.0417	**0.9021**	0.8813	2
	(0.1394)	(0.3470)	(0.0449)	(0.6436)	
Full Sample	**0.0656**	0.2506	**0.8838**	0.4827	1
	(0.0259)	(0.1626)	(0.0281)	(0.4872)	

[a] The p-value for J-test shown in parentheses.
[b] *overid* denotes the number of overidentifying restrictions.
[c] Bold entries denote estimate is significant at 5% level.
[d] Standard errors in parentheses.

Table 4.3: GMM Estimates using GMM_AIC: OECD Industry Groups

OECD	ϕ/μ	ε	η	J[a]	overid[b]
Nat. Resources	**1.1863**[c]	-0.1927	**0.9141**	0.1325	2
	(0.2596)[d]	(0.3326)	(0.0292)	(0.9359)	
Lab. Intensive	**0.0447**	**0.4240**	**0.8548**	1.2540	2
	(0.0199)	(0.1685)	(0.0458)	(0.5342)	
Scale Based	0.0472	**0.5637**	**0.7955**	1.5568	2
	(0.0287)	(0.2311)	(0.1162)	(0.4591)	
Prod. Diff.	**0.1396**	0.2573	**0.8365**	0.1421	2
	(0.0495)	(0.1526)	(0.0534)	(0.9314)	
Science Based	0.1525	0.0417	**0.9021**	0.8813	2
	(0.1394)	(0.3470)	(0.0449)	(0.6436)	
Full Sample	**1.0287**	0.7856	**0.9519**	3.3606	2
	(0.1913)	(0.7250)	(0.0150)	(0.1863)	

[a] The p-value for the J-test shown in parentheses.
[b] *overid* denotes the number of overidentifying restrictions.
[c] Bold entries denote estimate is significant at 5% level.
[d] Standard errors in parentheses.

Table 4.4: GMM Estimates using GMM_BIC: OECD Industry Groups

SIC802	ϕ/μ	ε	η	J[a]	overid[b]
Food & Bev.	**1.9344**[c]	1.1555	**0.9499**	0.6127	2
	(0.8656)[d]	(1.9401)	(0.0223)	(0.7391)	
Rubber & Plas.	**0.1900**	-0.4437	**0.9511**	0.2322	1
	(0.0376)	(0.9783)	(0.0447)	(0.6299)	
Leather	0.0087	**0.8039**	0.4926	0.0849	2
	(0.0185)	(0.3263)	(0.8589)	(0.9584)	
Textiles	**0.0763**	**0.5125**	**0.8459**	2.2708	2
	(0.0370)	(0.1745)	(0.0633)	(0.3213)	
Clothing	0.0004	0.9677	-1.1998	0.1995	1
	(0.0316)	(2.4780)	(169.0371)	(0.6551)	
Wood	**0.2486**	**0.3059**	**0.7803**	0.0069	1
	(0.0733)	(0.1089)	(0.0410)	(0.9337)	
Furn. & Fixt.	0.0640	**0.7301**	0.5575	0.5569	1
	(0.0491)	(0.2018)	(0.3922)	(0.4555)	
Paper	0.0868	-0.7227	**0.9776**	1.1845	2
	(0.0755)	(3.9226)	(0.0568)	(0.5531)	
Print. & Publ.	0.1267	-0.4894	**0.9456**	2.0463	2
	(0.0830)	(0.8792)	(0.0428)	(0.3595)	
Prim. Metals	0.1244	0.2346	**0.9137**	1.0980	2
	(0.0771)	(0.2735)	(0.0384)	(0.5775)	
Fabr. Metals	**0.1702**	0.2377	**0.8178**	0.6127	2
	(0.0487)	(0.1411)	(0.0499)	(0.7361)	
Machinery	0.0026	**0.9788**	-4.4134	2.3512	2
	(0.0365)	(0.2976)	(76.2013)	(0.3086)	
Transport.	0.0138	0.8584	0.1743	1.6054	2
	(0.0668)	(0.6300)	(3.6943)	(0.4481)	
Electrical	-0.0065	0.9461	-0.2183	0.0001	1
	(0.1299)	(1.0175)	(22.9402)	(0.9912)	
NonMet. Minerals	0.0472	**0.7415**	0.5848	0.0136	1
	(0.0701)	(0.3718)	(0.6434)	(0.9071)	
Petrol. & Coal	0.3300	-15.4718	**0.9978**	2.1961	2
	(0.2558)	(1566.5440)	(0.2136)	(0.3335)	
Chemicals	0.0170	**0.7962**	0.5258	0.1023	1
	(0.0129)	(0.1680)	(0.4189)	(0.7491)	
Instruments	**0.1733**	0.1969	**0.8413**	1.6421	2
	(0.0771)	(0.2533)	(0.0618)	(0.4400)	

[a] see the notes attached to Table 4.3

Table 4.5: GMM Estimates using GMM_AIC: 2-digit Industry Groups

SIC802	ϕ/μ	ε	η	J[a]	**overid**[b]
Food & Bev.	**1.9344**[c]	1.1555	**0.9499**	0.6127	2
	(0.8656)[d]	(1.9401)	(0.0223)	(0.7391)	
Rubber & Plas.	**0.1676**	0.2144	**0.8808**	2.6982	2
	(0.0377)	(0.1624)	(0.0381)	(0.2595)	
Leather	0.0087	**0.8039**	0.4926	0.0849	2
	(0.0185)	(0.3263)	(0.8589)	(0.9584)	
Textiles	**0.0763**	**0.5125**	**0.8459**	2.2708	2
	(0.0370)	(0.1745)	(0.0633)	(0.3213)	
Clothing	0.0170	0.4482	**0.8674**	3.885	2
	(0.0294)	(0.4645)	(0.1182)	(0.1431)	
Wood	**0.1482**	**0.4266**	**0.7828**	2.2022	2
	(0.0412)	(0.0981)	(0.0459)	(0.3225)	
Furn. & Fixt.	-0.0087	-0.1721	0.9561	9.0012	3
	(0.0411)	(26.4539)	(0.9735)	(0.0293)	
Paper	0.0868	-0.7227	**0.9776**	1.1845	2
	(0.0755)	(3.9226)	(0.0568)	(0.5531)	
Print. & Publ.	0.1267	-0.4894	**0.9456**	2.0463	2
	(0.0830)	(0.8792)	(0.0428)	(0.3595)	
Prim. Metals	0.1244	0.2346	**0.9137**	1.0980	2
	(0.0771)	(0.2735)	(0.0384)	(0.5775)	
Fabr. Metals	**0.1702**	0.2377	**0.8178**	0.6127	2
	(0.0487)	(0.1411)	(0.0499)	(0.7361)	
Machinery	0.0026	**0.9788**	-4.4134	2.3512	2
	(0.0365)	(0.2976)	(76.2013)	(0.3086)	
Transportation	0.0138	0.8584	0.1743	1.6054	2
	(0.0668)	(0.6300)	(3.6943)	(0.4481)	
Electrical	**-0.3419**	-2.8417	**0.9720**	6.1125	2
	(0.1677)	(14.4130)	(0.0902)	(0.0471)	
NonMet. Minerals	0.0637	0.6014	**0.7620**	3.1446	2
	(0.0683)	(0.4093)	(0.2744)	(0.2076)	
Petrol. & Coal	0.3300	-15.4718	**0.9978**	2.1961	2
	(0.2558)	(1566.5440)	(0.2136)	(0.3335)	
Chemicals	**0.4202**	-20.2798	**0.9442**	5.0444	2
	(0.1423)	(217.0442)	(0.0574)	(0.0803)	
Instruments	**0.1733**	0.1969	**0.8413**	1.6421	2
	(0.0771)	(0.2533)	(0.0618)	(0.4400)	

[a] see the notes attached to Table 4.3

Table 4.6: GMM Estimates using GMM_BIC: 2-digit Industry Groups

A.4 Appendix: Characteristics of Broad Industry Groups

A.4.1 Description

1. **Natural Resource Industries**[28]

    - primarily involved in processing of domestic raw materials
    - relatively larger materials share in output

2. **Labour Intensive Industries**

    - low physical capital to labour ratios
    - relatively larger labour share in output
    - relatively smaller plants and lower wages
    - generally protected by high tariff rates
    - relatively lower proportion of salaried employees

3. **Scale Based Industries**

    - relatively larger plants and higher wages
    - high physical capital to labour ratios
    - relatively larger labour share in output

4. **Product Differentiated Industries**

    - high advertising to sales ratios
    - producing a large number of products
    - relatively larger research and development (R & D) expenditures
    - relatively larger labour share in output

[28] see Baldwin & Raffiquzzaman 1994

5. **Science Based Industries**

   - high technology industries with high R & D expenditures
   - large percentage of workforce employed in scientific and professional occupations
   - larger plants and higher wages

A.4.2 OECD and 2-digit Industrial Sectors

1. **Natural Resource Industries**

   - Food & Beverages, Plastic Products, some Wood Industries, some Non-Metallic Mineral Products, and Refined Petroleum & Coal Products

2. **Labour Intensive Industries**

   - Textiles, Clothing, Furniture & Fixtures, some Wood Industries, and some Fabricated Metal products

3. **Scale Based Industries**

   - Rubber & Plastic, some Paper Industries, some Printing Industries, some Primary Metals industries, some Fabricated Metals industries, and some Transport Industries

4. **Product Differentiated Industries**

   - some Fabricated Metals industries, Machinery Industries, and some Electrical industries

5. **Science Based Industries**

   - some Electrical Industries, some Chemical Industries, and Instruments

5 Conclusions

This thesis has developed and estimated a structural model in which production experience is accumulated and stored by production units. Although variations in the stock of organizational capital might be an important source of plant productivity differences, a large portion of this thesis has concentrated upon the macroeconomic affects of allowing for the accumulation of organizational capital.

The interest in these macroeconomic affects is primarily motivated by the ability of this accumulation of organizational capital to generate an endogenous propagation mechanism beyond that associated with physical capital accumulation. Previous research has concentrated either upon accumulation by both households and production units or accumulation by households only. Consequently, the results presented in this thesis contribute to our knowledge of this endogenous propagation mechanism by focusing exclusively upon the accumulation of organizational capital by production units.

Treating the stock of organizational capital as a productivity enhancing factor of production implies that the accumulation of organizational capital might be associated with a production technology that exhibits increasing returns to scale. In this case, it is inappropriate to assume that production units operate in a perfectly competitive product market. The assumption of imperfectly competitive product markets introduces an important dynamic structure into the optimization problem of production units. When these production units face a downward sloping demand curve for their product, they recognize that charging a higher price today results in less output being sold. However, this lower output will also result in a lower stock of production experience in the future with consequently higher future costs of production. Fundamentally, these production units face a trade-off between maximizing current period profits and losing future productivity increases. It is this trade-off that has previously been ignored in existing studies of learning-by-doing.

Chapter 2 has detailed a structural model that might be used to study the accumulation of organizational capital in the aggregate economy. This structural model represents a particular decentralization of the planning solution presented in Cooper & Johri (2002). Using this structural model, this chapter has established that, when production experience is accumulated and stored by production units, the implied values of several key macroeconomic variables in the non-stochastic steady state might be quite different than those implied by an otherwise identical model that ignores the accumulation of organizational capital. It is has also been shown that the accumulation of production experience by households, as a by product of market work, might imply a different steady state compared to the accumulation of production experience as a joint product with the production of goods and services.

The macroeconomic effects of allowing for the accumulation of organizational capital can only be fully understood by also studying the dynamic response of the aggregate economy to exogenous disturbances that temporarily perturb the aggregate economy away from its steady state. Chapter 3 has examined the dynamic response of the aggregate economy to an exogenous unanticipated increase in government consumption. Since the interaction of this form of exogenous disturbance with the accumulation of production experience has not been studied previously, this chapter supplements our understanding of the endogenous propagation mechanism associated with the accumulation of organizational capital.

Chapter 3 has shown that, relative to a model that ignores the accumulation of organizational capital, the structural model is able to generate a hump-shaped dynamic response for output, for particular values of the organizational capital parameters. This suggests that the accumulation of production experience by production units will likely to be an important component of the endogenous propagation mechanism identified by Cooper & Johri (2002). This structural model is also able to generate a hump-shaped response in investment. A hump-shaped response in investment and output is an important feature of the empirical dynamic responses associated with the onset of a typical Ramey-Shapiro episode. More importantly, a model that ignores organizational capital is unable to produce dynamic responses in output and investment that exhibit this hump-shaped response. Consequently, at least qualitatively, the dynamic responses associated with the accumulation of organizational capital might be consistent with the stylized facts associated with the empirical responses.

Chapter 3 has also investigated the dynamic responses for a linear accumulation technology, compared to those for a log-linear accumulation technology. The results suggest that the endogenous propagation mechanism associated with the accumulation of organizational capital, and identified by Cooper & Johri (2002), probably does not critically depend upon the particular functional form assumed for the accumulation technology. Importantly, it is the accumulation of organizational capital and the resulting dynamic structure that it implies for the plant's maximization problem that generates this endogenous propagation mechanism rather than any specific functional form assumptions. This comparison between the aggregate implications associated with a linear or a log-linear accumulation technology provides a bridge between the largely macroeconomic literature that has used a log-linear technology and the largely microeconomic literature that has used a linear technology.

It is clear from Chapters 2 and 3 that the macroeconomic effects arising from the accumulation of organizational capital rely critically upon the existence of a dynamic structure, at the plant level, associated with the accumulation of organizational capital. The final chapter has presented an empirical evaluation of this dynamic structure using plant level data. Rather than directly estimating the production function (or the cost function), this final chapter has presented estimates of the organizational capital parameters using the first order conditions from a well-specified structural model of organizational capital. In addition, this chapter provides a method for estimating the contribution of organizational capital to plant level productivity using available plant level census data, while at the same time avoiding some of the commonly identified problems associated with the estimation of learning effects from production functions.

The results presented in this final chapter suggest that the dynamic structure of the model might be consistent with the plant level data. Consequently, this chapter provides evidence that, at the plant level, the hypothesis of organizational forgetting is likely to be empirically important for production units across a diverse range of (manufacturing) industries. Existing studies of learning-by-doing that aim to quantity the productivity of (accumulated) production experience without also considering the (endogenous) accumulation of this production experience are likely to be seriously flawed.

The results presented in the final chapter provide a microeconomic foundation for the macroeconomic implications of allowing for the accumulation of organizational capital discussed in Chapters 2 and 3. Importantly these result suggest that the internal propagation mechanism associated with the accumulation of organizational capital at the aggregate level, is supported by the plant level evidence.

One disadvantage of existing studies of learning-by-doing has been their restriction to specific industries or organizations primarily dictated by the need to construct measures of production experience since birth. In contrast, this chapter has detailed a method for estimating the contribution of organizational capital to plant level productivity using available plant level census data. Since the estimation does not require data on the stock of organizational capital, the estimation method considerably reduces the data requirements since there is no need to track production units from their birth. Consequently, this chapter uses a lengthy panel of annual observations for a large cross section of manufacturing establishments. This provides a bridge between the microeconomic evidence for learning-by-doing in specific industries and organizations and the aggregate results of Cooper & Johri (2002) and Johri & Letendre (2002) while at the same time using data collected at the plant level.

Interest in the economic implications of allowing for the accumulation of production experience is ultimately motivated by a desire to understand how economic policy should be conducted in the presence of organizational capital accumulation. Before any policy conclusions can be reached, it is necessary to understand whether the economic affects associated with the accumulation of experience by households are fundamentally different from the effects associated with the accumulation of experience by production units. Overall, the results presented in this thesis indicate that the accumulation of organizational capital by production units will likely be an important component of plant behaviour which has important implications for the response of the aggregate economy to exogenous disturbances. Consequently, continuing to ignore the implied dynamic structure associated with the accumulation of organizational capital by production units might lead to both microeconomic and stabilization policy prescriptions that are seriously flawed.

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