The Macroeconomic Effects of UK Tax, Regulation and R&D Subsidies: Testing Endogenous Growth Hypotheses in an Open Economy DSGE Model

by

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Abstract

This thesis investigates whether government policy had a causal impact on UK output and productivity growth between 1970 and 2009. Two policy-driven growth hypotheses are considered: first that productivity growth is systematically determined by the tax and regulatory environment in which firms start up and operate, and second that productivity is determined by direct subsidies to business R&D. Each growth hypothesis is embedded within an open economy Dynamic Stochastic General Equilibrium (DSGE) model calibrated to the UK experience; the agent's optimality conditions imply a reduced form linear relationship between policy and short-run productivity growth. Each model is tested by an Indirect Inference Wald Test, a simulation-based test which formally compares the data generated from the model with the observed data, using an unrestricted auxiliary model; the method has good power against general misspecification. Identification is assured for the DSGE model by the rational expectations restrictions; therefore the direction of causation in the model is unambiguously from policy to productivity. Both models are also estimated by Indirect Inference. Estimation results show that the tax and regulatory policy environment did have a causal effect on productivity and output in the 1970-2009 period, when policy is proxied by an index combining top marginal income tax rates and a labour market regulation indicator. The results are robust to changes in this proxy. Likewise, the hypothesis that productivity is driven by direct subsidies to business R&D is upheld in a 1981-2010 sample, though the results are weaker. This study offers unambiguous empirical evidence that temporary changes in policies underpinning the business environment can have long-lasting effects on economic growth.

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I dedicate this thesis to my family, most of all to my fantastic mum and dad.

Contents

Chapter 1

Introduction

The question of how growth is generated and whether it can be influenced by policy is still hotly debated among policymakers and academics, more than twenty-five years after Lucas declared the causes of growth an appropriate subject for obsession (Lucas, 1988).[1] In the intervening period, endogenous growth theories have proliferated. These theories hold that growth is determined through the optimising decisions of rational economic agents; if government policy can affect the decision margins of the individual, there is scope for it to affect the aggregate growth rate.

Some strong policy implications emerge from such models. For instance, Schumpeterian creative destruction models in the style of Aghion and Howitt (1992) recommend subsidies to the research sector, while the knowledge-spillover theory of entrepreneurship (Acs et al. 2009) recommends the removal of regulatory and tax-related obstacles to business start-up and operation, on the basis that such 'barriers to entrepreneurship' stifle growth. However, these recommendations are controversial. Subsidies, tax credits, tax rate cuts and deregulation all have potentially high up front costs to society, and conclusive empirical evidence that these policies stimulate economic growth at the macroeconomic level remains scarce.

One pervasive issue dogging empirical work in this area is model identification. Aggregate growth regressions in the style of Barro (1991) characterise policy as an exogenous variable,

[1] "Is there some action a government of India could take that would lead the Indian economy to grow like Indonesia's or Egypt's? If so, what, exactly? If not, what is it about the 'nature of India' that makes it so? The consequences for human welfare involved in questions like these are simply staggering: Once one starts to think about them, it is hard to think about anything else." (Lucas, 1988, p.5)

and growth rates are regressed on this and other control variables in a cross-country or panel setup. Such regression models are reduced forms of more complex relationships; since they lack restrictions, they can accommodate more than one underlying structural theory. For instance, we cannot distinguish between a model in which policy causes growth, and a model in which policy responds passively to economic expansion, itself driven by other processes.[2] The results are therefore uninformative on the effectiveness of policy. Other misgivings are expressed by Temple (1999), Durlauf et al. (2005) and Easterly (2005), among others. These centre on bias in the estimated relationships arising from parameter heterogeneity and omitted variables, and a general lack of robustness to outliers and changes in specification (regarding both the functional form, which is uncertain, and the set of covariates). Mankiw gave a scathing judgement on this literature in 1995, writing that "Policymakers who want to promote growth would not go far wrong ignoring most of the vast literature reporting growth regressions. Basic theory, shrewd observation, and common sense are surely more reliable guides for policy" (Mankiw, 1995, pp. 307-308). This opinion is mirrored by more recent comments by Rodrik (2012), and by Myles on the tax-growth literature, who writes that "Ultimately this line of research is a dead end if the aim is to understand what causes growth so that we can improve the situation" (Myles, 2009b, p.16), adding that "This is an area of research in which no progress appears to have been made" (*ibid.*, p.33).

A different approach to the macroeconometrics of policy and growth is therefore well overdue. Rodrik (2012) recommends that we "take the theories that motivate our empirical analyses more seriously. Our failure to undertake meaningful tests often derives from a failure to fully specify the theoretical model(s) being put to the test" (p.148). Having specified a structural model that embeds the hypothesis of interest, we must "come clean about what we assume is and is not observable, and inquire whether the empirical implications of such a model are consistent with the data" (p. 148). This thesis takes its cue from such statements.

Here I investigate the impact of certain policies on economic growth in recent UK history, looking at two hypotheses in turn. The first holds that tax and regulatory policy hinders total factor productivity growth by acting as a barrier to entrepreneurship; the second proposes that

[2] Instrumental variable strategies can go some way to addressing these issues, but finding an instrument that is both exogenous and strongly related to the policy of interest is not straightforward. Most potential instruments can be argued to be a direct cause of growth themselves.

direct government subsidies to private sector research and development (R&D) activity have a positive effect on productivity growth. For each of these hypotheses the existing literature points to theoretical ambiguity over the direction of causation in the policy-growth relationship, which undermines the interpretation of most empirical studies. I apply a simulation-based testing and estimation methodology to a structural model in which identification is assured, representing a novel approach to the issues.

Each hypothesis is examined within a dynamic stochastic general equilibrium (DSGE) model of the United Kingdom. The model's implied behaviour is formally tested at the aggregate level for its closeness to the UK experience through Indirect Inference, which uses an auxiliary model to describe both the simulated and the observed data; the statistical closeness of these descriptions is summarised in a Wald statistic. In this way we see whether the precisely specified causal relationships embedded in the DSGE model are rejected by the historical UK data. The approach throughout is therefore positivist – it is an attempt to see how the economic data we have was generated, not how the best potential outcome could be achieved. The positivist effort is a necessary step in the normative search for better policy, which always rests on modelling choices around the underlying setup.[3]

Traditionally, calibrated Real Business Cycle (RBC) models have been evaluated by an informal comparison of the moments of the simulated variables with the moments of the observed series, taken one at a time (e.g. Kydland and Prescott, 1982; also Chari et al., 2002). This indicates whether the model can replicate certain stylized facts. Indirect Inference follows a similar procedure, extending it to a formal statistical comparison of the joint behaviour of the variables, so ensuring that the model's implications for cross-moments are not neglected. It provides a formal evaluation criterion on which to judge the model's performance. Thus in contrast to the calibrationist stance that a DSGE model is inherently false and so "should not be regarded as a null hypothesis to be statistically tested", this study "take[s] the model seriously as a data-generating process" in confronting it with the data (Canova, 1994, p. S124). While

[3] Friedman noted this in 1953: "The conclusions of positive economics seem to be, and are, immediately relevant to important normative problems, to questions of what ought to be done and how any given goal can be attained" (p. 146). The assumption, that some would reject, is that of Keynes and Friedman that economics can be "a positive science . . . a body of systematized knowledge concerning what is" (Keynes, 1890, p.23); that is, we claim that searching for macroeconomic models that stand up to empirical tests is a worthwhile and important exercise.

calibrated studies of the macroeconomic impacts of policy reform are useful illustrations of the theories on which they are constructed, they give back the modeler's assumptions with little indication of their validity.

In addition to testing the starting calibration for each growth model, the structural parameters are estimated by Indirect Inference. This involves searching across the model's parameter space for the parameter set which minimises the test statistic, in a similar approach to Smith (1993) and Canova (1994, 2005). As the literature reviews make clear, strong priors do not exist for the calibration of the role of policy in the models, making this estimation procedure a necessary step for testing the hypotheses themselves rather than simply a particular numerical set of their parameters. This is the first time that the Indirect Inference methodology has been applied to a growth model of the UK. The study is conducted using unfiltered data for all endogenous variables. The two-sided filtering common in the RBC literature can alter the time series properties of the data (see e.g. Canova, 2014) and, mostly importantly in this context, may remove short- to medium-run changes in growth, interpreting them as changes in underlying potential. Since these transitional growth episodes are precisely what we wish to investigate here with respect to policy variation, filtering would incur the loss of significant information from the data.

The Indirect Inference estimation results in Chapter 5 show that the tax and regulatory policy environment did have a causal effect on productivity and output in the 1970-2009 period, when the policy environment is proxied by an equally weighted combination of the top marginal rate of personal income tax and a labour market regulation indicator (itself constructed from a survey-based centralised collective bargaining indicator and an index of the marginal cost of hiring calculated by the World Bank). This conclusion is robust to adjustments around the policy variable, continuing to hold when the small companies rate of corporate tax is used in place of the top marginal income tax rate, and when tax rates are excluded altogether. Further, the model performs strongly on the Wald test when more endogenous variables are added to the auxiliary model, explaining real interest rate and real exchange rate behaviour as well as physical capital, labour supply and consumption in various combinations. The test and estimation results in Chapter 7 also provide positive support for the hypothesis that productivity is driven by direct subsidies to private sector R&D for a 1981 to 2010 sample, though this model is rejected when other important endogenous variables are added to the auxiliary model, making the evidence for it less strong. Variance decompositions for both estimated models show that the policy variable is responsible for much of the endogenous variables' simulated variance, due to its permanent effects on non-stationary productivity. The power of the Indirect Inference test to reject a false hypothesis is high (Le et al. 2011, 2015), so these results taken together constitute strong empirical support for the hypothesis that UK government policy had a causal effect on total factor productivity growth in the past thirty to forty years, in particular through framework policies underpinning the business environment.

The thesis is structured as follows. In Chapter 2, an open economy DSGE model of the UK is described as a testing vehicle for both policy-driven growth hypotheses. From the model's optimality conditions, a systematic relationship between productivity and policy is derived, according to which persistent but temporary shocks to policy around trend permanently shift the level of productivity, also generating a short- to medium-run growth episode above productivity's deterministic drift. Hence this is strictly a 'semi-endogenous' growth model in the sense of Jones (1995b), as policy is not assumed to determine long-run growth rates in steady state. A starting calibration is proposed, and the model is used to generate impulse response functions which illustrate the real business cycle and growth behaviour of the model after a controlled policy shock. Chapter 3 outlines the Indirect Inference Methodology. The subject of Chapters 4 and 5 is the relationship between tax and regulatory policy, entrepreneurship and aggregate productivity; Chapter 4 reviews the literature on this relationship, while Chapter 5 presents the associated empirical work. The following two chapters deal similarly with the relationship between direct subsidies to business R&D and productivity, with a literature review in Chapter 6 and empirical work in Chapter 7. Chapter 8 presents a welfare analysis of a one-off 1% policy shock in each model in turn, and Chapter 9 concludes the thesis.

Chapter 2

A Model with Policy-Driven Productivity

Here I present the DSGE model that is the basis for empirical work in the rest of the study. It is an open economy Real Business Cycle model adapted from Meenagh et al. (2010), with the addition of an endogenous growth process based on Meenagh et al. (2007). Meenagh et al. (2010) suggest that a model of this type with exogenous growth can explain UK real exchange rate behaviour without the assumption of nominal rigidities in the style of Obstfeld and Rogoff (1995) or Chari et al. (2002). This has been chosen as an appropriate backdrop against which to examine the relationship in the UK data between certain government policies and macroeconomic aggregates. The endogenous growth process is similar to Lucas (1990), in that productivity growth depends on investments of time in innovative activity. While growth in Lucas (1990) is driven by human capital accumulation, here the growth mechanism is less specifically defined, characterised ultimately by the policy variable assumed to govern incentives surrounding it; in Chapters 5 and 7, policy variables are chosen to equate the innovative activity, in turn, to entrepreneurial activities and to formal research and development. Below, a systematic function relating non-stationary productivity to this policy variable (in general terms) is derived from the representative agent's optimising behaviour. The policy variable is modelled as a trend stationary process, and the focus is on how temporary shocks perturbing the policy around its long run trend can lead to permanent effects on the level of productivity;

since these temporary shocks are highly persistent, their impacts on the level are long-lasting, leading to medium-run growth episodes, though the long run rate of productivity growth is unchanged. Therefore this is not strictly an endogenous growth model in the sense of the New Endogenous Growth Theory (see Solow, 1994), in that policy cannot affect the balanced growth path of the economy but has transitional and reasonably long-lasting effects on growth, as well as permanent effects on the level.

The model is presented in Section 2.1. Then a baseline calibration is outlined in Section 2.2, followed by a discussion of the impulse response functions generated from a policy shock.

2.1 The Model

Outlined below is a two country Armington-style model, with a single industry (Armington, 1969). Thus there is one broad type of consumption good traded at the international level, but the product of the home goods sector is differentiated from that of the foreign country; consumers demand both the home good and the imported good, but there is scope for preference bias towards the home good. The home country here is identified with the UK economy and the foreign country represents the rest of the world; its size therefore allows us to treat its prices and consumption demand as exogenous. International markets are cleared by movements in the real exchange rate.

In the home country, there is one representative consumer, a representative profit-maximising firm operating in a perfectly competitive final goods market (the only sector in the economy), and a government which spends on the consumption good and raises funds through taxation and through bond issue. The price-taking consumer chooses to consume, hold savings instruments, and divide time among competing activities in order to maximise utility subject to time and budget constraints. The price-taking firm hires workers and finances its capital purchases by issuing bonds. The consumer is also the shareholder of the firm. Productivity growth is a non-stationary process with systematic dependence on the level of time spent in an activity z_t, itself a choice variable of the representative consumer. This activity is subject to a proportional cost due to government policy.

2.1.1 Consumer Problem

A representative consumer chooses paths for consumption (C_t) and leisure (x_t) to maximise her lifetime utility, represented by the function U:

$$U = \max E_0[\sum_{t=0}^{\infty} \beta^t u(C_t, x_t)] \tag{2.1}$$

where $u(.)$ takes the following additively separable form.

$$u(C_{t,}x_t) = \theta_0 \frac{1}{(1-\rho_1)} \gamma_t C_t^{(1-\rho_1)} + (1-\theta_0) \frac{1}{(1-\rho_2)} \xi_t x_t^{(1-\rho_2)} \tag{2.2}$$

$\rho_1, \rho_2 > 0$ are the Arrow-Pratt coefficients of relative risk aversion for consumption and leisure, respectively, the inverse of ρ_1 (ρ_2) being the intertemporal substitution elasticity between consumption (leisure) in two consecutive periods. γ_t and ξ_t are preference shocks, and $0 < \theta_0 < 1$ is a preference weighting on consumption.

The agent divides time among three activities: leisure, labour N_t supplied to the firm for the real wage w_t, and an activity z_t that is unpaid at t but known to have important future returns. This is summarised in the time constraint (the time endowment is normalised at one):

$$N_t + x_t + z_t = 1 \tag{2.3}$$

The choice of z_t is left aside for now; I return to this in Section 2.1.5 on endogenous growth. This section outlines the agent's choices of leisure versus non-leisure activity, consumption, savings instruments in the form of domestic and foreign bonds (b_{t+1}, b^f_{t+1}) and a bond issued by the firm to finance its capital investment ($\tilde{b}_{t+1}$), and new shares (S^p_t) purchased at the current price (q_t). All bonds with time subscript $t+1$ are issued at a unit price at t, and pay out one plus the rate of interest agreed at t in the following period. The agent receives income at t in the form of labour wages ($w_t N_t$), maturing bonds, and dividends (d_t) on share holdings purchased last period, holding additional purchasing power from the current sales value of her shareholdings which is $q_t S^p_{t-1}$. The agent is also liable for a taxbill T_t, which will be defined further below. Since z_t is the only taxed choice variable in the model, with all other taxes treated as lump sum and adjusting to rule out any wealth effects, the taxbill is not relevant at this stage of the problem. The agent's real terms budget constraint is as follows, with the price P_t of the consumption bundle normalised to unity.

$$\begin{gathered} C_t + b_{t+1} + Q_t b^f_{t+1} + q_t S^p_t + \tilde{b}_{t+1} = w_t N_t - T_t + b_t(1 + r_{t-1}) + \\ Q_t b^f_t(1 + r^f_{t-1}) + (q_t + d_t)S^p_{t-1} + (1 + \hat{r}_{t-1})\tilde{b}_t \end{gathered} \tag{2.4}$$

where Q_t is a unit free measure of the price of the foreign consumption good relative to the general price level at home defined as $Q_t = \frac{P^f_t}{P_t}.\hat{E}_t$. $\hat{E}_t$ is the nominal exchange rate (the domestic currency value of one unit of foreign currency). The variable Q_t therefore moves inversely to the real exchange rate, generally thought of as the price of exports relative to the price of imports. The foreign bond b^f_{t+1} is a real bond, in that it costs the amount of money that a unit of the foreign consumption basket (C^*_t) would cost, i.e. P^*_t, where P^*_t is the foreign CPI. In terms of the domestic currency, this is $P^*_t\hat{E}_t$. Given that everything is the budget constraint is relative to P_t, and assuming that $P^*_t \simeq P^f_t$ (i.e. exported goods from the home country have little impact of the larger foreign country) the unit cost of the real foreign bond is Q_t. The domestic bond is likewise equivalent in value to a unit of the home consumption basket.

I abstract from the nominal exchange rate $\hat{E}_t$ throughout the analysis, assuming $\hat{E}_t \equiv \hat{E}$ and normalising $\hat{E}$ at one, so that Q_t is treated as the import price relative to the domestic CPI. For fixed $\hat{E}$, a rise in Q_t implies a real depreciation of the domestic good on world markets and hence an increase in the competitiveness of domestic exports; this can be thought of as a real exchange rate depreciation.

The consumer maximises his utility (equations 2.1 and 2.2) with respect to C_t, x_t, b_{t+1}, b^f_{t+1}, $\tilde{b}_{t+1}$ and S^p_t, subject to his time and budget constraints (equations 2.3 and 2.4). The Lagrangian is

$$\begin{gathered} L_0 = E_0 \sum_{t=0}^{\infty} \beta^t E_t \{ \tfrac{\theta_0}{1-\rho_1} \gamma_t C_t^{(1-\rho_1)} + \left(\tfrac{1-\theta_0}{1-\rho_2}\right) \xi_t x_t^{(1-\rho_2)} - \\ \lambda_t [C_t + b_{t+1} + Q_t b^f_{t+1} + q_t S^p_t + \tilde{b}_{t+1} - w_t N_t + T_t - \\ b_t(1 + r_{t-1}) - Q_t b^f_t(1 + r^f_{t-1}) - (q_t + d_t)S^p_{t-1} - (1 + \hat{r}_{t-1})\tilde{b}_t]\} \end{gathered} \tag{2.5}$$

and the problem yields the following first order conditions:

$$C_t \quad : \quad 0 = \gamma_t \theta_0 C_t^{-\rho_1} - \lambda_t \tag{2.6}$$

$$x_t \quad : \quad 0 = \xi_t (1-\theta_0) x_t^{-\rho_2} - \lambda_t w_t \tag{2.7}$$

$$b_{t+1} \quad : \quad 0 = -\lambda_t \beta^t + \lambda_{t+1} \beta^{t+1} (1+r_t) \tag{2.8}$$

$$b_{t+1}^f \quad : \quad 0 = -\lambda_t \beta^t Q_t + \lambda_{t+1} \beta^{t+1} E_t Q_{t+1} (1+r_t^f) \tag{2.9}$$

$$\tilde{b}_{t+1} \quad : \quad 0 = -\lambda_t \beta^t + \lambda_{t+1} \beta^{t+1} (1+\hat{r}_t) \tag{2.10}$$

$$S_t^p \quad : \quad 0 = -\lambda_t \beta^t q_t + \lambda_{t+1} \beta^{t+1} (q_{t+1} + d_{t+1}) \tag{2.11}$$

The first order conditions for C_t and b_{t+1} combine for the Euler equation, describing intertemporal substitution in consumption. The price of an extra unit of utility from consumption today is $\frac{1}{(1+r_t)}$ in terms of tomorrow's expected consumption utility discounted by time preference.

$$\frac{1}{(1+r_t)} \gamma_t C_t^{-\rho_1} = \beta E_t [\gamma_{t+1} C_{t+1}^{-\rho_1}] \tag{2.12}$$

The intratemporal condition follows from the f.o.c. for C_t and x_t.

$$\frac{U_x}{U_c}|_{U=0} = \frac{(1-\theta_0)\xi_t x_t^{-\rho_2}}{\theta_0 \gamma_t C_t^{-\rho 1}} = w_t \tag{2.13}$$

This equates the marginal rate of substitution between consumption and leisure to their price ratio, the real wage - the price of consumption is the numeraire[1]. The optimality conditions for b_{t+1}^f and b_{t+1} yield the real uncovered interest parity condition (RUIP), so that any difference between the domestic and foreign real interest rates is offset by an expected appreciation in the real exchange rate.

$$(1+r_t) = E_t \frac{Q_{t+1}}{Q_t} (1+r_t^f) \tag{2.14}$$

The first order conditions on $\tilde{b}_{t+1}$ and b_{t+1} combine to show that $\hat{r}_t = r_t$, equating the real rate of return on the firm's bond to the domestic real interest rate. From the conditions for S_t^p and b_{t+1} we find the share price formula. Forward substitution in this formula reveals that q_t

[1] Later it will be shown that the return on time spent in labour, w_t, is equal at the margin to the return on z_t, the alternative non-leisure activity.

reflects the present value of the firm's future profit (i.e. dividend) stream per share.

$$q_t = \frac{q_{t+1} + d_{t+1}}{(1 + r_t)} = \sum_{i=1}^{\infty} \frac{d_{t+i}}{\prod_{j=0}^{i-1} (1 + r_{t+j})} \tag{2.15}$$

The condition in equation 2.15 rests on the further assumption that q_t does not grow faster than the interest rate, $\lim_{i \to \infty} \frac{q_{t+i}}{\prod_{j=0}^{i-1}(1+r_{t+j})} = 0$. These first order conditions show that the returns on all assets (S_t^p, b_{t+1}, $\tilde{b}_{t+1}$ and b_{t+1}^f) must be equal at the margin - the prices move to ensure that this is so.

This two-country model assumes that the domestic country has a single, perfectly competitive final goods sector, producing a version of the final good that is differentiated from the product of the (symmetric) foreign industry. It is therefore a single-industry version of the Armington model (Armington, 1969; see also Feenstra, Luck, Obstfeld and Russ, 2014). The Armington model assumes a multi-level utility structure: the consumer obtains utility from consuming an overall amount of each industry product 'type' (in this one-industry case that is simply C_t) and she allocates her budget between each type of good accordingly; she then decides how to divide that spending allocation across the differentiated products within that group (here C_t^d and C_t^f).[2] Differentiated products of a given type yield utility to the agent via a CES sub-function and it is to this sub-utility maximisation problem we now turn: having discovered the agent's optimally chosen amount of C_t for the level-one utility maximisation, we can treat it as a parametric value and consider how that amount of the consumption bundle should break down between consumption of the domestic variety, C_t^d, and the foreign variety, C_t^f. The level of consumption C_t chosen above must satisfy the expenditure constraint on consumption,

$$C_t = p_t^d C_t^d + Q_t C_t^f \tag{2.16}$$

where p_t^d and Q_t are domestic and foreign prices relative to the general price level, P_t. To reiterate, the nominal exchange rate has been fixed at unity, and Q_t is the ratio of foreign

[2] Thus although at the industry level individual firms operate in an intensely competitive environment, on world markets the firm sector in a particular country is the sole source of that variety of the final good, implying potential for monopoly power at the international level.

prices to the domestic CPI multiplied by the nominal exchange rate so as to make it a unit free measure. P_t is a weighted combination of import and export prices corresponding to the Consumer Price Index.[3] Given the identity in equation 2.16, the consumer chooses C_t^d and C_t^f to maximise $\tilde{C}_t$ according to the following CES aggregator utility function (equation 2.17), subject to the constraint that $\tilde{C}_t \leqslant C_t$.

$$\tilde{C}_t = [\omega(C_t^d)^{-\rho} + (1-\omega)\varsigma_t(C_t^f)^{-\rho}]^{-\frac{1}{\rho}} \tag{2.17}$$

At the point of the maximum the constraint is binding, so that the consumption-equivalent utility, $\tilde{C}_t$, is equal to the amount spent on consumption goods, C_t (the variable that appears in the budget constraint of the main consumer problem). The assumption here is that domestic consumers have some fixed preference bias towards the domestic good, reflected in the parameter ω; $0 < \omega < 1$. The demand for imports is subject to a stochastic shock, ς_t . The elasticity of marginal substitution between domestic and foreign varieties of the good is constant at $\sigma = \frac{1}{1+\rho}$. The Lagrangian for the problem is M,

$$M = [\omega(C_t^d)^{-\rho} + (1-\omega)\varsigma_t(C_t^f)^{-\rho}]^{-\frac{1}{\rho}} + \mu(C_t - p_t^d C_t^d - Q_t C_t^f) \tag{2.18}$$

and the first order conditions are[4]:

$$C_t^d : 0 = \omega C_t^{(1+\rho)}(C_t^d)^{-(1+\rho)} - \mu p_t^d \tag{2.19}$$

$$C_t^f : 0 = (1-\omega)\varsigma_t C_t^{(1+\rho)}(C_t^f)^{-(1+\rho)} - \mu Q_t \tag{2.20}$$

Since at the maximum, $\tilde{C}_t = C_t$, and $\frac{d\,M}{d\,C_t} = \mu$ while $\frac{d\,M}{d\,\tilde{C}_t} = 1$, it follows that $\mu = 1$ when the constraint binds. Hence the relative demand for the imported good is given by equation 2.21 and the relative demand for the domestic consumption good by equation 2.22.

$$\frac{C_t^f}{C_t} = \left(\frac{(1-\omega)\varsigma_t}{Q_t}\right)^{\sigma} \tag{2.21}$$

[3] This would be a CES function but it is left out here since we do not need it for the analysis.

[4] Using the substitution $[\omega(C_t^d)^{-\rho} + (1-\omega)\varsigma_t(C_t^f)^{-\rho}]^{-\frac{1}{\rho}-1} = \{[...]^{-\frac{1}{\rho}}\}^{(1+\rho)} = C_t^{(1+\rho)}$

$$\frac{C_t^d}{C_t} = \left(\frac{\omega}{p_t^d}\right)^{\sigma} \tag{2.22}$$

2.1.2 Open economy relations

Given equation 2.21 above, the symmetric equation describing foreign demand for domestic goods (exports) relative to general foreign consumption is

$$(C_t^d)^* = C_t^* \left(\left(1-\omega^F\right)\varsigma_t^*\right)^{\sigma^F} (Q_t^*)^{-\sigma^F} \tag{2.23}$$

where * signifies a foreign variable and ω^F and σ^F are respectively the foreign equivalents to home bias and the elasticity of marginal substitution between domestic and imported goods. Q_t^* is the foreign equivalent of Q_t, the ratio of the import price to the CPI. By symmetry, $Q_t^* = \frac{P_t^d}{P_t^*}$, so that $\ln Q_t^* = \ln p_t^d - \ln P_t^*$. Since $Q_t = \frac{P_t^f}{P_t}$, and P_t is the numeraire, $Q_t = P_t^f$. Adding the assumption that $P_t^* \simeq P_t^f$ on the basis that the domestic export goods price has little influence on the foreign CPI means that $\ln Q_t^*$ depends on $\ln p_t^d$ and Q_t.

An expression for p_t^d as a function of Q_t follows from the maximised equation 2.17 where $\tilde{C}_t = C_t$ combined with the relative demand functions 2.21 and 2.22:

$$1 = \omega^{\sigma}(p_t^d)^{\rho\sigma} + [(1-\omega)\varsigma_t]^{\sigma} Q_t^{\rho\sigma} \tag{2.24}$$

A loglinear approximation for this expression is derived by taking a first order Taylor expansion around a point where $p^d \simeq Q \simeq \varsigma \simeq 1$, with $\sigma = 1$. This yields

$$\ln p_t^d = \hat{k} - \frac{1-\omega}{\omega}\frac{1}{\rho}\ln\varsigma_t - \frac{1-\omega}{\omega}\ln Q_t \tag{2.25}$$

where $\hat{k}$ is a constant of integration.

Returning to export demand, it was established above that

$$\ln(C_t^d)^* = \ln C_t^* + \sigma^F \ln\left(1-\omega^F\right) + \sigma^F \ln\varsigma_t^* - \sigma^F \ln p_t^d + \sigma^F \ln Q_t$$

since $\ln Q_t^* = \ln p_t^d - \ln Q_t$. Given the relationship in 2.25, this is

$$\ln(C_t^d)^* = \ln C_t^* + \sigma^F \ln\left(1-\omega^F\right) + \sigma^F \ln \varsigma_t^* - \sigma^F(\hat{k} - \frac{1-\omega}{\omega}\frac{1}{\rho}\ln\varsigma_t) + \frac{1}{\omega}\sigma^F \ln Q_t$$

The export demand equation is then

$$\ln(C_t^d)^* = \check{c} + \ln C_t^* + \sigma^F \frac{1}{\omega} \ln Q_t + \varepsilon_{ex,t} \tag{2.26}$$

where $\check{c}$ collects the constants and $\varepsilon_{ex,t} = \sigma^F \ln \varsigma_t^* + \sigma^F \frac{1-\omega}{\omega}\frac{1}{\rho}\ln\varsigma_t$.

Assuming no capital controls, the real balance of payments constraint is satisfied so that the current account surplus (real net exports plus income flows on foreign assets) and capital account deficit (the decrease in net foreign assets) sum to zero. In other words, for net saving or asset accumulation in period t the country must run a trade surplus. Expressed in real terms, the balance of payments is

$$\Delta b_{t+1}^f = r_t^f b_t^f + \frac{p_t^d EX_t}{Q_t} - IM_t \tag{2.27}$$

2.1.3 Firm Problem

There is a representative firm which produces a homogeneous consumption good using constant returns to scale production technology, with diminishing marginal products to labour and capital inputs. Production is described by the following Cobb Douglas function, where A_t is total factor productivity:

$$Y_t = A_t K_t^{1-\alpha} N_t^{\alpha} \tag{2.28}$$

The firm also faces convex adjustment costs to capital which are assumed, for the sake of tractability, to take a quadratic form. The firm undertakes capital investment in this model, raising the necessary funds to purchase new capital not by issuing new shares (the number of shares is fixed at one) but by issuing debt ($\tilde{b}_{t+1}$) at t, the cost of which is $\hat{r}_t$ payable along with the face value at $t+1$. Bonds are issued one for one with units of capital demanded:

$$\tilde{b}_{t+1} = K_t$$

The cost of capital covers not only the return demanded by debt-holders, but also capital depreciation δ and adjustment costs, represented by $\tilde{a}_t$ [5]. The firm's profit function is:

$$\pi_t = Y_t - \tilde{b}_{t+1}(\hat{r}_t + \delta + \kappa_t + \tilde{a}_t) - (\tilde{w}_t + \chi_t)N_t$$

where κ_t and χ_t are shocks to the net rental costs of capital and labour, respectively - these could capture random movements in marginal tax rates, for instance in depreciation allowances or national insurance. It was shown using the consumer first order conditions above (2.8 and 2.10) that $\hat{r}_t = r_t$. Substituting in the constraint that $\tilde{b}_{t+1} = K_t$, and that the cost of the bond is r_t, the profit function is in 2.29

$$\pi_t = Y_t - K_t(r_t + \delta + \kappa_t) - \frac{1}{2}\zeta(\Delta K_t)^2 - (\tilde{w}_t + \chi_t)N_t \tag{2.29}$$

Here adjustment costs are explicit, having substituted $\tilde{b}_{t+1}\tilde{a}_t = K_t\tilde{a}_t = K_t.\frac{1}{2}\zeta\frac{(\Delta K_t)^2}{K_t} = \frac{1}{2}\zeta(\Delta K_t)^2$.

The firm maximises expected profits subject to these constraints, through its choices of capital (K_t) and labour (N_t), taking prices r_t and $\tilde{w}_t$ (the respective real rental rates of capital and labour) as given. Assume free entry into the sector and a large number of firms operating under perfect competition. The Lagrangian for the problem is $\mathcal{L}_0$:

$$\mathcal{L}_0 = E_0 \sum_{t=0}^{\infty} d^t E_t \left\{ Y_t - K_t(r_t + \delta + \kappa_t) - \frac{1}{2}\zeta(\Delta K_t)^2 - (\tilde{w}_t + \chi_t)N_t \right\} \tag{2.30}$$

ζ is a multiplicative constant affecting adjustment costs, while d is the firm's discount factor (these parameter allow some empirical flexibility when the model is calibrated). The first order conditions are:

$$K_t \quad : \quad 0 = \frac{Y_t}{K_t}(1-\alpha) - (r_t + \delta + \kappa_t) - \zeta(K_t - K_{t-1}) + d\zeta(E_t K_{t+1} - K_t) \tag{2.31}$$

$$N_t \quad : \quad 0 = \frac{Y_t}{N_t}.\alpha - (\tilde{w}_t + \chi_t) \tag{2.32}$$

Equation 2.31 sets the marginal product of capital (net of the cost of input adjustment and

[5] where the adjustment cost attached to $\tilde{b}_{t+1}$ is: $\tilde{b}_{t+1}\tilde{a}_t = \tilde{b}_{t+1}.\frac{1}{2}\zeta\left(\tilde{b}_{t+1} + \frac{\tilde{b}_t^2}{\tilde{b}_{t+1}} - 2\tilde{b}_t\right) = \tilde{b}_{t+1}.\frac{1}{2}\zeta\frac{(\Delta\tilde{b}_{t+1})^2}{\tilde{b}_{t+1}} = \frac{1}{2}\zeta(\Delta\tilde{b}_{t+1})^2$

depreciation) equal to its unit price, plus a cost shock.

$$(1-\alpha)\frac{Y_t}{K_t} - \delta - \zeta \Delta K_t + d\zeta E_t(\Delta K_{t+1}) = r_t + \kappa_t \tag{2.33}$$

It can be rearranged to give a non-linear difference equation in capital.

$$K_t = \frac{1}{1+d}K_{t-1} + \frac{d}{1+d}E_t K_{t+1} + \frac{(1-\alpha)}{\zeta(1+d)}\frac{Y_t}{K_t} - \frac{1}{\zeta(1+d)}(r_t+\delta) - \frac{1}{\zeta(1+d)}\kappa_t \tag{2.34}$$

This equation could be described as the demand for capital, its non-linearity resulting from the quadratic capital adjustment costs that the firm faces. Given capital demand from equation 2.34, the firm's investment, I_t, follows via the linear capital accumulation identity (equation 2.35).

$$K_t = I_t + (1-\delta)K_{t-1} \tag{2.35}$$

The first order condition with respect to labour equates the marginal product of labour to its price, the real unit cost of labour to the firm ($\tilde{w}_t$) plus the stochastic cost shock term χ_t. This is rearranged for the firm's demand for labour condition.

$$N_t = \alpha . \frac{Y_t}{\tilde{w}_t + \chi_t} \tag{2.36}$$

Throughout this exposition of the firm's problem the notation for the rental rate of labour, $\tilde{w}_t$, has differed from the real wage referred to in the consumer problem, w_t. In this Armington-style open economy the domestic firm sector produces a variety of the final good that is differentiated from the product variety of the foreign firm sector, therefore facing an elastic demand curve in world markets (Armington, 1969). Hence although the representative firm is a price-taker operating in a perfectly competitive sector within the domestic economy, at the country level Q the home price (relative to foreign prices which are exogenous) is set to clear the domestic market in goods. This assumption of differentiated goods introduces a wedge between the consumer real wage, w_t, and the real unit cost of labour from the perspective of the firm, $\tilde{w}_t$. The real rental price of labour faced by the domestic firm is the nominal wage W_t relative to the unit value of the domestic good produced, P_t^d, while the real wage in the consumer budget constraint is the nominal wage W_t relative to the *general* price level, the price P_t of the consumption bundle which combines both domestic and imported goods (P_t is treated as the numeraire throughout). Since $p_t^d \equiv \frac{P_t^d}{P_t}$, the wedge can be expressed as

$$p_t^d = \frac{w_t}{\tilde{w}_t} \tag{2.37}$$

implying, via 2.25, the relationship in equation 2.38.

$$\ln w_t = \hat{k} + \ln \tilde{w}_t - \left(\frac{1-\omega}{\omega}\right)^{\sigma} \ln Q_t - \left(\frac{1-\omega}{\omega}\right)^{\sigma} \frac{1}{\rho} \ln \varsigma_t \tag{2.38}$$

2.1.4 Government

The government spends on the consumption good (G_t), which is assumed to be non-productive and made up strictly of welfare transfers, subject to its budget constraint.

$$G_t + b_t(1 + r_{t-1}) = T_t + b_{t+1} \tag{2.39}$$

where T_t is revenue collected from consumers. As well as raising tax revenues the government borrows, issuing bonds maturing one period ahead; a bond issued in period t at a unit price is denoted b_{t+1}, paying out $(1+r_t)$ times its face value at $t+1$. Each period the government raises tax revenues to cover spending on transfer payments and the current bill for debt interest, so that $T_t = G_t + r_{t-1}b_t$ and $b_t = b_{t+1}$. Therefore the level government debt is assumed fixed in this model and the government is fully solvent in every period. Revenue T_t is made up as follows.

$$T_t = \tau_t z_t + \Phi_t \tag{2.40}$$

τ_t is a proportional rate on time spent in innovative activity z_t. This could be a penalty representing costs incurred by the innovator not just due to direct monetary taxes or fees levied by the government but also due to time and costs associated with regulatory compliance. If we assume that all policy costs on z_t are genuine external social costs, redistributed to the consumer by the government via a reduction in the lumpsum levy Φ_t, then the tax revenue collected by government is equal to that taxbill paid by consumers.[6] Alternatively τ_t could be

[6] It is possible that only a proportion $0 < \psi < 1$ of the penalty paid on z_t by the innovator enters the government budget as revenue, the rest being deadweight loss that reduces the payoff to innovation activities

a negative tax, such as subsidy measures to incentivise the innovative activity; this scenario is investigated in Chapter 7. By construction in this model, a higher penalty (or lower subsidy) on z_t leads to less of this activity and consequently more standard labour (or leisure) for a given real wage, while a lower tax (or higher subsidy) should lead to a greater investment of time in z and so higher productivity growth, ceteris paribus. This relation is examined in more detail in Section 2.1.5. The remainder of government revenue is collected by Φ_t, a lumpsum tax capturing the revenue effects of all other tax instruments affecting the consumer. Φ_t responds to changes in $\tau_t z_t$, adjusting to keep tax revenue neutral in the government budget constraint. Government spending is modeled as an exogenous trend stationary AR(1) process.

$$\ln G_t = g_o + g_1 t + \rho_g \ln G_{t-1} + \eta_{g,t} \tag{2.41}$$

where $\mid \rho_g \mid < 1$ and $\eta_{g,t}$ is a white noise innovation.

2.1.5 Endogenous Growth

Assume that productivity growth is a linear function of time spent in some innovation-enhancing activity z_t.

$$\frac{A_{t+1}}{A_t} = a_0 + a_1 z_t + u_t \tag{2.42}$$

$$d \ln A_{t+1} = (a_0 - 1) + a_1 z_t + u_t \tag{2.43}$$

where $a_1 > 0$. z_t is the systematic channel through which policy incentives, τ_t, can drive growth[7]. The characterisation of z_t in practice depends on the data used for its tax, and on certain elements of calibration. It will become clear from manipulation of its first order condition that z_t can be bypassed altogether in the model, since productivity growth ultimately depends on the tax variable τ'_t alone (equation 2.53). This section derives the linear relationship between productivity growth and τ'_t that drives the RBC model's dynamic behaviour in simulations.

The model is conceptually similar to Lucas (1988, 1990), where growth is determined endoge-

without benefiting the consumer in other ways. In that case revenue is $\tilde{T}_t = \psi \tau_t z_t + \Phi_t$ while the consumer tax bill is $T_t = \tau_t z_t + \Phi_t$. Here ψ is assumed to be 1, though notionally it could vary stochastically.

[7] All other factors that might systematically affect growth - such as human capital or firm specific R&D investment - are therefore in the error term.

nously by the agent's decision to devote a proportion of time to human capital accumulation. Once accumulated, human capital enhances labour efficiency in the production process and increases earnings, though in the short term the return to labour (for a given level of human capital) must be foregone in order to raise the human capital stock. Thus there is a tradeoff in terms of how a unit of time can be allocated; as an input to the human capital production function, as an input to goods production, or in leisure. The particular endogenous growth process used here is from Meenagh et al. (2007), adapted for a decentralised framework.

Earlier the consumer utility maximisation problem was developed for all control variables except z_t, the choice of time spent in innovative activities, so we now turn to that decision margin, taking all other choices as given. The consumer maximises utility in equations 2.1 and 2.2 with respect to z_t, subject to budget and time constraints (equations 2.3 and 2.4) as before. The Lagrangian L_0 is repeated here for convenience (cf. equation 2.5); now the taxbill is made explicit (eq. 2.40) in the budget constraint. I add a further assumption that in every period t, the consumer's shareholdings are equivalent to a single share, i.e. 2.44 holds for all t.

$$S^p_{t-1} = S^p_t = \bar{S} = 1 \tag{2.44}$$

This is not to say that the consumer makes no decision to hold shares in every period; each period the consumer demands S^p_t and the price per share must be such that the number of shares supplied (normalised at one for all t) are held by the consumer. The value per share given in equation 2.15 is then the value of the firm as a whole. The assumption in 2.44 allows the substitution to be made in the budget constraint that $q_t S^p_t - (q_t + d_t) S^p_{t-1} = -d_t$.

$$\begin{aligned} L_0 = E_0 \sum_{t=0}^{\infty} \beta^t E_t \{ & \tfrac{\theta_0}{1-\rho_1} \gamma_t C_t^{(1-\rho_1)} + \left(\tfrac{1-\theta_0}{1-\rho_2}\right) \xi_t x_t^{(1-\rho_2)} - \lambda_t [C_t + b_{t+1} + Q_t b^f_{t+1} + \\ & \tilde{b}_{t+1} + \tau_t z_t + \Phi_t - w_t N_t - b_t(1+r_{t-1}) - Q_t b^f_t (1 + r^f_{t-1}) - (1+\hat{r}_{t-1})\tilde{b}_t - d_t] \} \end{aligned} \tag{2.45}$$

Note that the dividend income d_t received by the shareholder is everything leftover from revenue after labour and capital input costs are paid, i.e. profits.

It is worth saying something here about how the rational agent expects z_t to raise his own consumption possibilities. This hinges on his role as the firm's sole shareholder. Given the relationship in equation 2.42, the agent is aware that a marginal change in z_t will result in permanently higher productivity from period $t+1$. This higher productivity is fully excludable and is donated exclusively by the agent to the atomistic firm he owns; the productivity increase is then anticipated to raise household income through higher firm profits paid out as dividends. The agent assumes that his choice here will not affect economy-wide aggregates; all prices are taken as parametric (note that the productivity increase is not anticipated to increase the consumer real wage here, though it will do so in general equilibrium). Annex 1 contains more discussion of this.

Given the time endowment $1 = N_t + x_t + z_t$, a full set of optimality conditions for time allocations will describe the agent's indifference relations between z_t and x_t, between x_t and N_t, and between z_t and N_t. Once two have been found, the third follows. We have already derived the margin at which the agent is indifferent between spending a unit of time in x_t and a unit in N_t (the intratemporal condition in 2.13); here I focus on the decision margin between z_t and N_t, so that the margin between z_t and x_t is implied. Therefore the substitution $N_t = 1 - x_t - z_t$ can be made in the budget constraint.[8]

The first order condition is given in equation 2.46:

$$\frac{dL}{dz_t} = 0 = -\beta^t \lambda_t w_t - \beta^t \lambda_t \tau_t + E_t \sum_{i=1}^{\infty} \beta^{t+i} \lambda_{t+i} . \frac{d\ d_{t+i}}{dz_t} \tag{2.46}$$

Note that τ_t may be negative if it represents a subsidy to z_t. At the (N_t, z_t) margin, the optimal choice of z_t trades off the impacts of a small increase dz_t on labour earnings (which will be lower in period t, due to reduced employment time), the innovation costs to be paid (higher at t in proportion to the increase in z_t), and expected dividend income. Given equation 2.42, $\frac{dA_{t+i}}{dA_{t+i-1}} = \frac{A_{t+i}}{A_{t+i-1}}$. Therefore, for $i \geq 1$,

$$\frac{d\ A_{t+i}}{dz_t} = \frac{d\ A_{t+i}}{dA_{t+i-1}} . \frac{d\ A_{t+i-1}}{dA_{t+i-2}} ..... \frac{d\ A_{t+2}}{dA_{t+1}} . \frac{d\ A_{t+1}}{dz_t} = A_{t+i} \frac{A_t}{A_{t+1}} a_1 \tag{2.47}$$

[8] If we were to examine the (x_t, z_t) margin we would substitute $x_t = 1 - N_t - z_t$ in the utility function. This would just yield the relationship that we can deduce from the intratemporal condition between the MRS (x_t, C_t) and the returns on z_t. Intuitively, the agent has preferences for leisure and consumption over all t, and the consumption path is funded by non-leisure activity - either labour, or z_t. We look first of all at the possibility that all consumption is funded by the proceeds of N_t. This gives the intratemporal condition, where $\frac{MUx}{MUC} = w$. That is, the opportunity cost of x_t is the real wage, the proceeds of labour foregone. The opportunity cost of x_t (from the perspective of z_t foregone) is also the return on z_t, the value of higher permanent income from $t+1$ onwards, less the penalty incurred at t. These opportunity costs must be equated.

so that $\frac{dd_{t+i}}{dz_t} = \frac{Y_{t+i}}{A_{t+i}} A_{t+i} \frac{A_t}{A_{t+1}} a_1$. See Annex 1 for a full explanation of the expected effect of dz_t on the firm's profit function at $t+1$ (and for any $t+i$). Equation 2.46 becomes

$$\beta^t \lambda_t (w_t + \tau_t) = E_t \sum_{i=1}^{\infty} \beta^{t+i} \lambda_{t+i} . \frac{Y_{t+i}}{A_{t+i}} . A_{t+i} \frac{A_t}{A_{t+1}} . a_1$$

We can rearrange this so that the return to N_t and the return to z_t are equal at the margin, in terms of utility from consumption.

$$\beta^t \lambda_t w_t = \frac{a_1}{a_0 + a_1 z_t + u_t} . E_t \sum_{i=1}^{\infty} \beta^{t+i} \lambda_{t+i} Y_{t+i} - \beta^t \lambda_t \tau_t \tag{2.48}$$

On the left hand side, the return on the marginal unit of N_t is of course the real consumer wage; on the right is the present discounted value of the expected increase in the dividend stream as a result of a marginal increase in z_t, net of the contemporaneous costs associated with innovative activities which are captured in this model by τ_t.[9] τ_t therefore stands for the extent to which the returns from higher productivity resulting from z_t are not appropriated by the innovator responsible for generating them or, when it represents a subsidy, the extent to which innovation costs are reduced by government intervention.

Equation 2.48 can be rearranged for z_t, substituting for the multiplier using the first order condition for consumption, equation 2.6.

$$z_t = \frac{1}{\beta^t} \frac{E_t \sum_{i=1}^{\infty} \beta^{t+i} \gamma_{t+i} C_{t+i}^{-\rho_1} Y_{t+i}}{\gamma_t C_t^{-\rho_1} (w_t + \tau_t)} - \frac{(a_0 + u_t)}{a_1} \tag{2.49}$$

From equation 2.42,

$$a_1 z_t = \frac{A_{t+1}}{A_t} - (a_0 + u_t)$$

[9] The non-policy cost of generating new productivity via z_t is assumed to be zero. τ_t does not include any fixed or sunk cost of innovating. Moreover, time in z_t leads in a certain fashion to higher productivity, except in so far as the relationship is subject to a random shock.

Equation 2.49 then becomes

$$\frac{A_{t+1}}{A_t} = a_1 . \frac{E_t \sum_{i=1}^{\infty} \beta^i \gamma_{t+i} C_{t+i}^{-\rho_1} Y_{t+i}}{\gamma_t C_t^{-\rho_1} (w_t + \tau_t)} \tag{2.50}$$

Modeling the preference shock to consumption, γ_t, as an AR(1) stationary process such that $\gamma_t = \rho_\gamma \gamma_{t-1} + \eta_{\gamma,t}$, a substitution can also be made for $E_t \sum_{i=1}^{\infty} \gamma_{t+i}$ as i goes to infinity.

$$E_t \sum_{i=1}^{\infty} \gamma_{t+i} = \gamma_t \sum_{i=1}^{\infty} \rho_\gamma^i$$

Setting $\rho_1 \simeq 1$ and approximating $\frac{C_t}{Y_t}$ as a random walk (see Appendix 1, Section A), so that $E_t \frac{Y_{t+i}}{C_{t+i}} = \frac{Y_t}{C_t}$ for all $i > 0$, the expression becomes

$$\frac{A_{t+1}}{A_t} = a_1 . \frac{\frac{\beta \rho_\gamma}{1-\beta \rho_\gamma} \cdot \frac{Y_t}{C_t}}{\frac{w_t}{C_t} (1 + \tau'_t)} \tag{2.51}$$

where $\frac{\tau_t}{w_t} \equiv \tau'_t$. This refocuses the driver variable as the ratio of the penalty rate on time spent in z_t to the current wage level, which is the opportunity cost of spending time outside the regular workforce. τ'_t is a unit free measure with the dimensions of a tax rate, as opposed to τ_t which, like the wage, is an amount of money payable on units of time. This variable τ'_t is easier to take to the data.

A first order Taylor expansion of the righthand side of equation 2.51 around a point where $\frac{Y_t}{w_t} = \frac{Y}{w}$ and $\tau'_t = \tau'$ gives

$$\frac{A_{t+1}}{A_t} = a_1 . \frac{\frac{\beta \rho_\gamma}{1-\beta \rho_\gamma} \frac{Y}{w}}{(1 + \tau')} + a_1 . \frac{\frac{\beta \rho_\gamma}{1-\beta \rho_\gamma}}{(1 + \tau')} d \frac{Y_t}{w_t} - a_1 . \frac{\frac{\beta \rho_\gamma}{1-\beta \rho_\gamma} \frac{Y}{C}}{\frac{w}{C} (1 + \tau')^2} d\tau'_t \tag{2.52}$$

Equivalently, for a model assuming subsidies to increase innovation i.e. with an opposite signed effect (see Chapters 6 and 7), this relationship is:

$$\frac{A_{t+1}}{A_t} = a_1 . \frac{\frac{\beta \rho_\gamma}{1-\beta \rho_\gamma} \frac{Y}{w}}{(1 - s')} + a_1 . \frac{\frac{\beta \rho_\gamma}{1-\beta \rho_\gamma}}{(1 - s')} d \frac{Y_t}{w_t} + a_1 . \frac{\frac{\beta \rho_\gamma}{1-\beta \rho_\gamma} \frac{Y}{C}}{\frac{w}{C} (1 - s')^2} ds'_t$$

where the policy variable is called s'_t in order to distinguish it explicitly from the penalty variable τ'_t. Treating the ratio $\frac{Y}{w}$ as roughly time invariant - on the basis that $\frac{w_t}{Y_t} = \alpha.N_t$ and labour N_t is a long-run stationary variable - and modeling the policy variable as stationary, a linear relationship exists between $\frac{A_{t+1}}{A_t}$ and τ'_t of the form

$$d\ln A_{t+1} = b_0 + b_1\tau'_t + \varepsilon_{A,t} \tag{2.53}$$

where $b_1 = -a_1.\frac{\frac{\beta\rho_\gamma}{1-\beta\rho_\gamma}\frac{Y}{C}}{\frac{w}{C}(1+\tau')^2}$ for a policy raising the costs of innovation. Alternatively $b_1 = a_1.\frac{\frac{\beta\rho_\gamma}{1-\beta\rho_\gamma}\frac{Y}{C}}{\frac{w}{C}(1-s')^2}$ for a subsidy policy in the equivalent relationship, $d\ln A_{t+1} = b_0 + b_1 s'_t + \varepsilon_{A,t}$. Note that this relationship came out of the first order condition for z_t. The household makes its z_t choice taking all other sources of productivity growth as exogenous; other growth factors outside the model (like human capital accumulation) therefore affect the constant b_0 and the error term in the productivity time series. Equation 2.53 drives the behaviour of the model in simulations. Calibration of b_1 is discussed in Section 2.2 and in Chapter 5. To summarise the process gone through between equations 2.42 and 2.53, we have used the productivity growth hypothesis with the agent's optimal choice of z_t to derive productivity growth as a linear function of τ'_t (or s'_t), the percentage 'tax' (or subsidy) rate on z_t.

Examination of the relationship in equation 2.49 reveals a relationship between z_t and τ'_t. Define $\frac{\partial z_t}{\partial \tau'_t} \equiv c_1$, and assume this to be a constant. This parameter enters the simulation explicitly in the producer real wage equation, derived as follows from the intratemporal condition (equation 2.13) which governs labour supply choices. Taking the total derivative of the time endowment in 2.3 gives $dx_t = -dN_t - dz_t$, and hence $\frac{dx_t}{x_t} = \frac{-dN_t - dz_t}{x_t}$. Assuming that $\bar{N} \approx \bar{x} \approx \frac{1}{2}$ in some initial steady state with approximately no z activity implies

$$\frac{dx_t}{\bar{x}} = d\ln x_t \approx -d\ln N_t - \frac{dz_t}{\bar{N}} = -d\ln N_t - 2dz_t \tag{2.54a}$$

In log differences, the intratemporal condition is

$$-\rho_2 d\ln x_t = -d\ln \xi_t + d\ln \gamma_t - \rho_1 d\ln C_t + d\ln w_t \tag{2.54b}$$

Substituting for $\ln w_t$ from 2.38 (dropping the constant) and using 2.54a, this becomes

$$\begin{aligned} d\ln N_t + 2c_1 d\tau_t' = -\tfrac{1}{\rho_2} d\ln\xi_t + \tfrac{1}{\rho_2} d\ln\gamma_t - \tfrac{\rho_1}{\rho_2} d\ln C_t + \\ \tfrac{1}{\rho_2}\left[k + d\ln\tilde{w}_t - \tfrac{1}{\rho}\left[\tfrac{1-\omega}{\omega}\right]^{\sigma} d\ln\varsigma_t - \left[\tfrac{1-\omega}{\omega}\right]^{\sigma} d\ln Q_t\}\right] \end{aligned} \tag{2.54c}$$

Integrating this and rearranging for the log of the real unit cost of labour to the firm, $\ln\tilde{w}_t$, gives

$$\ln\tilde{w}_t = const_4 + \rho_2 \ln N_t + \rho_1 \ln C_t + \left[\frac{1-\omega}{\omega}\right]^{\sigma} \ln Q_t + \rho_2 2c_1\tau_t' + e_{w,t} \tag{2.55}$$

where

$$e_{w,t} = -\ln\gamma_t + \ln\xi_t + \frac{1}{\rho}\left[\frac{1-\omega}{\omega}\right]^{\sigma} \ln\varsigma_t \tag{2.56}$$

i.e. the unit labour cost shock is a combination of preference shocks to consumption and leisure and to import demand. When τ_t' represents a penalty on innovative activities, $c_1 < 0$ and hence $\frac{d\ln\tilde{w}_t}{d\tau_t'} < 0$ and equally $\frac{d\ln N_t}{d\tau_t'} > 0$, since equation 2.55 is simply the labour supply condition rearranged; so the worker's response to a higher penalty rate on z_t is to raise time spent in ordinary employment. Conversely when τ_t' is replaced by a subsidy s_t' or other financial incentive towards innovative activities, the signs of these effects are reversed. Taking the derivative of the relationship in 2.49 shows $c_1 = -\frac{\frac{\beta\rho_\gamma}{1-\beta\rho_\gamma}\frac{Y_t}{C_t^{\rho_1}}}{\frac{w_t}{C_t^{\rho_1}}(1+\tau_t')^2}$, or $c_1 = \frac{\frac{\beta\rho_\gamma}{1-\beta\rho_\gamma}\frac{Y_t}{C_t^{\rho_1}}}{\frac{w_t}{C_t^{\rho_1}}(1-s_t')^2}$ in the subsidy case.

To be clear, what has been done here is the following. I took the optimal condition governing the (x, N) margin (equation 2.13) and substituted in from the time endowment to relate the marginal rate of substitution between x and C to the amount of time left for N and z (given the optimal x choice). The amount of time chosen for x is of course consistent with the time endowment. Moreover I evaluate the time endowment at some point where the proportions of time given to N and x are roughly equal at a half (this is somewhat arbitrary). I then substitute in for the real consumer wage using the expression for the wedge between w_t and $\tilde{w}_t$ (equation 2.38). I also use the relationship between z and τ' in 2.49 to substitute out dz_t in terms of $d\tau_t'$. This leaves the relationship in 2.55.

2.1.6 Closing the model

Goods market clearing is required to close the model. In volume terms, the supply of the domestic good is equated to the demand for consumption (net of imports), investment, government consumption and exports.

$$Y_t = C_t + I_t + G_t + EX_t - IM_t \tag{2.57}$$

Relative prices (i.e. the real exchange rate, linked to the real interest rate through RUIP) move to ensure that market clearing also holds in value terms. Since the goods market clears and income can be spent only on goods or assets, by Walras' Law the overall assets market must also clear.

$$\Delta S_t + \Delta b^f_{t+1} + \Delta b_{t+1} + \Delta \tilde{b}_{t+1} = \Delta S^{p,D}_t + \Delta b^{f,D}_{t+1} + \Delta b^D_{t+1} + \Delta \tilde{b}^D_{t+1} \tag{2.58}$$

Change in demand for assets on the right hand side is equated to changes in supply on the left by movements in the asset returns; since marginal returns are equal across different asset types (by virtue of their first order conditions) we can refer to a single asset return, r_t. Equality in the overall asset market signifies that total savings equals total investment. Given the government budget constraint is balanced in every period and the government keeps the domestic bond stock fixed ($\Delta b_{t+1} = 0$), government savings are zero. Therefore total private savings equal total investment. Private investment is made up of domestic investment demand and net foreign investment (i.e. negative holdings of b^f_t). The price q_t ensures that the domestic shares market clears in every period

$$S^p_t = S_t \tag{2.59}$$

so $\Delta S_t = \Delta S^{p,D}_t$ (and $S_t = \bar{S}$). Thus

$$\Delta b^f_{t+1} + \Delta \tilde{b}_{t+1} = \Delta b^{f,D}_{t+1} + \Delta \tilde{b}^D_{t+1} \tag{2.60}$$

Since $\Delta \tilde{b}_{t+1} = \Delta K_t$, and both capital and labour markets are cleared by their respective prices, the market for the firm's bond clears: $\Delta \tilde{b}^D_{t+1} = \Delta \tilde{b}_{t+1}$. Walras' Law implies that the market for foreign bonds also clears, so that domestic demand for foreign savings vehicles is equal to supply: $\Delta b^f_{t+1} = \Delta b^{f,D}_{t+1}$.

A transversality condition is also required to ensure a balanced growth equilibrium is reached for this open economy in which trade deficits (surpluses) cannot be run forever via borrowing from (lending) abroad. This rules out a growth path financed by insolvent borrowing rather than growing fundamentals. The transversality condition imposes the restriction on the balance of payments identity that in the long run the change in net foreign assets (the capital account) must be zero. At some notional terminal date T when the real exchange rate is constant, the cost of servicing the current level of debt must be met by an equivalent trade surplus.

$$r_T^f b_T^f = -\left(\frac{p_T^d.EX_T}{Q_T} - IM_T\right) \tag{2.61}$$

This is the only transversality condition in the model, and the numerical solution path is forced to be consistent with the constraints it places on the rational expectations. In practice it is a constraint on household borrowing since government solvency is ensured already by other means, and firms do not borrow from abroad.

When solving the model, the balance of payments constraint is scaled by output so that the terminal condition imposes that the ratio of debt to gdp must be constant in the long run, $\Delta\hat{b}_{t+1}^f = 0$ as $t \to \infty$, where $\hat{b}_{t+1}^f = \frac{b_{t+1}^f}{Y_{t+1}}$. This implies that the growth rate of debt equals the growth rate of real gdp (g_Y). The solvency condition on international borrowing strictly demands that the real rate of interest on foreign bonds (r^f) is higher than the growth rate of debt (g_Y) as $t \to \infty$. This is because solvency requires that the present value of debt held at T goes to zero, $\frac{b_T^f}{(1+r^f)^T} \to 0$, as $T \to \infty$. Knowing that at T debt is growing at g_Y,

$$\frac{b_T^f}{(1+r^f)^T} = \frac{b_0^f(1+g_Y)^T}{(1+r^f)^T} = b_0^f(1+g_Y-r^f)^T \tag{2.62}$$

For this to go to zero, we require $r^f > g$. Note that imposing $\Delta\hat{b}_{T+1}^f = 0$ does not ensure $r^f > g$ in the long run. We must assume that $r^f > g$ holds. If it did not hold the economy would be in a state of dynamic inefficiency; when $r^f < g$ it is irrational not to borrow more, since investment will yield growth which more than covers the cost of investment. Logically speaking, borrowing should increase until $r^f > g$. This issue is out of scope here.

2.1.7 Stochastic processes

There are eleven auto-regressive (AR) shocks in the model. Seven of these are residuals in the structural equations, and four are exogenous variables. Just one of the eleven is non-stationary (the productivity shock) while the rest are I(0), either straightforwardly stationary or trend stationary. All stationary residuals take the following AR(1) form:

$$e_{i,t} = a_i + b_i t + \rho_i e_{i,t-1} + \eta_{i,t} \tag{2.63}$$

where $\eta_{i,t}$ is an i.i.d mean zero innovation term, and i identifies the endogenous variable to which the residual belongs. The exogenous variables take a similar form. The AR(1) coefficients ρ_i are estimated using the residuals backed out of the structural model, given the calibration. To back out the model's structural residuals where expectations enter, expectational variables are estimated using a robust instrumental variable technique due to Wickens (1982) and McCallum (1976); they are the one step ahead predictions from an estimated VECM. Where $a_i \neq 0$ and $b_i \neq 0$, the linearly detrended residual $\hat{e}_i$ is used, where

$$\hat{e}_{i,t} = \rho_i \hat{e}_{i,t-1} + \eta_{i,t} \tag{2.64}$$

and

$$\hat{e}_{i,t} = e_{i,t} - \hat{a}_i - \hat{b}_i t \tag{2.65}$$

The innovations $\eta_{i,t}$ are approximated by the fitted residuals from estimation of equation 2.64, $\hat{\eta}_{i,t}$.[10] These are then used to bootstrap the model. New innovation series are created by drawing from these residuals with replacement, drawing by time vector (i.e. horizontally) so as to preserve any contemporaneous correlation between them. One exception to this is the policy variable which is bootstrapped separately, on the basis that contemporaneous correlation between this shock and the separate, exogenous productivity shock would hamper the identification of the growth hypothesis. Further discussion of the bootstrapping methodology is deferred to Chapter 3.

There are I(0) shocks to domestic interest rates, labour demand, capital, the real producer

[10] In Chapters 5 and 7, the trend terms $b_i t$ form the basis for the deterministic growth path over the sample period, which is added back into simulated paths generated by the model before those paths are formally compared to the real data in the Wald statistic, via the auxiliary model (the VECM). Since for each residual the linear trend is estimated in isolation rather than jointly, we can expect some inaccuracy in these deterministic growth terms. For this reason the model is not assessed on its ability to capture these trends which, though included in the auxiliary model, are left out of the Wald statistic. More is said of this in Chapter 3.

wage (or unit cost of labour), exports and imports. Foreign interest rates, foreign consumption, government spending and τ'_t (or s'_t) are stochastic exogenous variables that are also treated as stationary AR(1) processes. The Solow residual A_t is modelled as a unit root process with drift driven by an AR(1) shock and by exogenous variable τ'_t or s'_t, based on equation 2.53.[11]

$$A_t = d + A_{t-1} + b_1 \tau_{t-1} + e_{A,t} \tag{2.66}$$

$$e_{A,t} = \rho_A e_{A,t-1} + \eta_{A,t} \tag{2.67}$$

Since the drift term in productivity is exogenous and the penalty variable τ'_t is moving stochastically around a constant mean, the long run growth rate of A_t in the absence of any shocks is constant. Although N_t is stationary and cannot grow in steady state, $Y_t = F(K_t, A_t N_t)$ will grow at a constant rate when K_t and $A_t N_t$ grow at the same rate along a balanced growth path, and the balanced growth rate of A_t could theoretically rise if the steady state proportion of time z_t could be increased, which would in turn require the steady state level of τ to decrease. However, that is not the focus in the present paper. A balanced growth path of the model is assumed to exist, in that at some notional future date when all shocks have ceased, variables settle down to constant growth rates that are functions of deterministic trends or drift terms in the residuals; but the steady state growth behaviour of the economy in our finite sample is not the empirical issue of interest. The aim here is to look at how productivity growth changes along the model's transition path as it is shocked out of equilibrium, in particular by policy shocks to the incentive structures governing certain innovative activities; we focus on entrepreneurial activities and on R&D. The non-stationarity of productivity implies that even temporary shocks to incentives will have a permanent effect on the level, and a stream of positive shocks would raise the productivity growth rate over the corresponding period.

[11] The growth rate of productivity may itself be non-stationary – A_t is certainly non-stationary, and could be I(1) or I(2). If τ'_t and the shock are both stationary, productivity will be I(1), but if τ'_t is I(1) then the productivity level A_t would be I(2). An I(2) productivity process would make the whole model I(2), which does not necessarily match the facts - though unit root tests have been shown to have limited power to demonstrate order of integration conclusively when it is borderline. The penalty rate is a pure exogenous variable which can be modelled at our discretion; the model should be rejected if we make the wrong choice. Since the index seems to have some trended behaviour we can characterise it as trend stationary.

2.1.8 The Log-Linearised Model

The linearised system of optimality conditions and constraints solved numerically to obtain paths for the endogenous variables as functions of the exogenous shocks is given below. Each equation is normalised on one of the endogenous variables. All variables are in natural logs, except where variables are already expressed in percentages (e.g. $\hat{b}_t^f$, which is the ratio of net foreign assets to output). See Appendix 2 for data descriptions and symbol key. The solution method with non-stationary data is explained in Appendix 1, Section A. For notational clarity, $\ln(C_t^d)^*$ and $\ln C_t^f$ have been replaced with $\ln EX_t$ and $\ln IM_t$, respectively.

$$r_t = r' + \rho_1 (E_t \ln C_{t+1} - \ln C_t) + e_{r,t} \tag{2.68}$$

$$\ln Y_t = \alpha \ln N_t + (1-\alpha) \ln K_t + \ln A_t \tag{2.69}$$

$$\ln N_t = \ln Y_t - \tilde{w}_t + e_{n,t} \tag{2.70}$$

$$\ln K_t = \zeta_1 \ln K_{t-1} + \zeta_2 \ln K_{t+1} + \zeta_3 \ln Y_t - \zeta_4 . r_t + e_{k,t} \tag{2.71}$$

$$\ln C_t = \frac{\bar{Y}}{\bar{C}} \ln Y_t - \frac{EX}{\bar{C}} \ln EX_t + \frac{IM}{\bar{C}} \ln IM_t - \frac{\bar{K}}{\bar{C}} \ln K_t + (1-\delta-\gamma_k)\frac{\bar{K}}{\bar{C}} \ln K_{t-1} - \frac{\bar{G}}{\bar{C}} \ln G_t \tag{2.72}$$

$$\ln \tilde{w}_t = \rho_2 \ln N_t + \rho_1 \ln C_t + \left[\frac{1-\omega}{\omega}\right]^{\sigma} \ln Q_t + \rho_2 2 c_1 \tau'_t + e_{wh,t} \tag{2.73}$$

$$\ln w_t = \ln \tilde{w}_t - \left[\frac{1-\omega}{\omega}\right]^{\sigma} \ln Q_t + e_{w,t} \tag{2.74}$$

$$\ln EX_t = \ln C^*_t + \sigma^F \frac{1}{\omega} \ln Q_t + e_{X,t} \tag{2.75}$$

$$\ln IM_t = \ln C_t - \sigma \ln Q_t + e_{M,t} \tag{2.76}$$

$$\ln Q_t = E_t \ln Q_{t+1} + r^f_t - r_t \tag{2.77}$$

$$\Delta \hat{b}^f_{t+1} = (r^f_t - g)\hat{b}^f_t + \left(\frac{1}{1+g}\right)\left(\begin{array}{c} \frac{EX}{\tilde{Y}} . \frac{\tilde{p}^d}{\tilde{Q}} \ln EX_t - \frac{EX}{\tilde{Y}} . \frac{\tilde{p}^d}{\tilde{Q}} \frac{1}{\omega} \ln Q_t \\ - \frac{IM}{\tilde{Y}} \ln IM_t \end{array}\right) \tag{2.78}$$

$$\ln A_t = \ln A_{t-1} + b_1 \tau'_{t-1} + e_{A,t} \tag{2.79}$$

$$\ln C^*_t = \rho_{C^*} \ln C^*_{t-1} + \eta_{C^*,t} \tag{2.80}$$

$$\ln G_t = \rho_G \ln G_{t-1} + \eta_{G,t} \tag{2.81}$$

$$r^f_t = \rho_{rf} r^f_{t-1} + \eta_{rf,t} \tag{2.82}$$

$$\tau'_t = \rho_\tau \tau'_{t-1} + \eta_{\tau,t} \tag{2.83}$$

Note that in the model tested in Chapter 7, the variable s'_t replaces τ'_t in equations 2.73, 2.79 and 2.83. Three of these equations hold as identities (market clearing, real uncovered interest parity and the balance of payments), and the consumer wage shock is also set to zero (it has common elements with the shock to v_t, see equations 2.38 and 2.56). The last four equations describe the exogenous variables: foreign consumption demand, government consumption demand, foreign interest rates and the policy variable. The shocks $e_{i,t}$ are ARIMA(1,0,0) processes, where i

denotes the endogenous variable on which the relevant equation has been normalised.

Where equations are not straightforwardly linear in logs, they are linearised around sample mean values, denoted by the overbar. The capital demand equation and market clearing constraint contain intertemporal dynamics; these equations are linearised around a point at which $K_t = \bar{K}$, and K_{t-1} and K_{t+1} are related to $\bar{K}$ by a fixed balanced growth rate γ_k. Likewise, the balance of payments constraint is scaled by output and its linearisation therefore includes the parameter g, the assumed balanced growth rate of output. An additional assumption applied in the linearisation of the balance of payments is that $\hat{k} = \frac{1-\omega}{\omega}\frac{1}{\rho}\ln\varsigma_t = 0$ in equation 2.84, allowing the following approximation:

$$\ln p_t^d - \ln Q_t = -(\frac{1-\omega}{\omega} + 1)\ln Q_t = -\frac{1}{\omega}\ln Q_t \tag{2.84}$$

Whether these approximations are good enough is an empirical matter.

Why choose not to filter the data?

Since Nelson and Plosser (1982), there has been significant interest in the possibility that macroeconomic time series variables are non-stationary; that is, their moments depend on time in a way that is at least partly unpredictable. In much of the real business cycle literature the approach has been to stationarise data before using it to solve or test the implications of a model, by filtering out trends (both deterministic and stochastic elements) using a Hodrick-Prescott (HP) or Band Pass procedure (Hodrick and Prescott, 1997; Baxter and King, 1999). While many have acknowledged the difficulties presented by HP filtering (Canova, 2014), it is still a dominant practice. The HP filter separates a time series into a cyclical component and a trend component, the latter reflecting underlying 'potential' while the cycle reflects temporary deviations from it. The trend is obtained by smoothing the series using a two-sided moving average, for which the degree of smoothness is arbitrarily specified. Anything not satisfying this smoothness criterion is extracted and termed business cycle volatility. When the focus is on stochastic growth behaviour, however, it does not seem appropriate to decompose a time series arbitrarily into a 'long run potential' component and fluctuations around it. Those fluctuations would correspond in this model to short-run or 'transitional' growth episodes in the data;

those are of crucial interest in this study and we would want to be sure they are extracted accurately, but there is some reason to think that HP filtering would not achieve that. First of all, these transitional periods following a shock may be reasonably long and, secondly, there may occasionally be large shocks. In both cases the HP filter generates distortion in the estimates of underlying trends, and because it is a two-sided process, these distortions occur both before and after the shock. Thus where we would want to analyse the adjustment of the model to the shock, the HP filter may interpret it as a change in underlying potential and remove it. In general, it can induce spurious autocorrelations and variability in the series individually and spurious comovement between series - in other words it alters the time series properties of the data (Canova, 2014). It is therefore inappropriate to use data stationarised in this way for this applied work on the short- and medium-run growth impacts of policy, just as it is inappropriate for models of crisis (e.g. Le et al. 2014).

I am interested in testing what is strictly speaking a 'semi-endogenous' growth process (cf. Jones, 1995b), since the hypothesis does not make the strong claims of the New Endogenous Growth theory that policy systematically affects the long-run balanced growth rate. So the emphasis is not on a long-run relationship between the growth rate of productivity and the policy variable, but on the short- to medium-run dependency of productivity growth changes on policy shocks. Such policy shocks are temporary, and the policy variable itself is modelled as stationary around some long run level; however, policy shocks have the effect of permanently shifting the level of productivity, generating an episode of productivity growth above its long run deterministic drift rate. Through their impact on non-stationary productivity, temporary policy shocks therefore affect the behaviour of all the endogenous variables in their transition back to long run trend, as well as having a permanent impact on the level to which they will converge. This is illustrated in the impulse response functions below.

Since, by definition in the model, changes over time are not driven solely by an exogenous trend but by permanent productivity responses to temporary changes in policy, stationarising the data in a potentially distortive way may obscure some of the interactions of interest; we certainly do not want to remove the stochastic trend from the model. Therefore unfiltered data is used for the endogenous variables when solving, testing and estimating the model. Only the exogenous variables are detrended where they are modelled as stationary, as described in the previous section.

2.2 Calibration and impulse response functions

In this section I present a starting calibration and a set of impulse response functions (IRFs) to illustrate the internal logic of the model, using the data described in Appendix 2. The IRFs represent the response of the solved endogenous variables to a controlled one-off shock. IRFs were analysed for all 11 of the exogenous shock processes, and they produce behaviour consistent with the existing RBC literature. Here the analysis focuses on growth policy, so only the shock to the policy variable is discussed.

The data chosen for the policy variable, τ_t', play an important role in the study. The growth channel z_t itself is not included in simulations of the model, so τ_t' should reflect policies which incentivise (or disincentivise) the innovation activity specified in the chosen hypothesis. In Chapters 5 and 7 the data used to proxy policy are discussed in more detail. Here the policy variable used to illustrate the model's behaviour is the ratio of government funded business expenditure on R&D (BERD) to the total BERD from all funding sources. This represents direct subsidies to R&D performed by the private sector. Therefore the marginal effects of policy on the innovative activity and on productivity - c_1 and b_1, respectively - are both positive. These IRFs are representative of all policy variables used in later chapters; all have been examined, and none have qualitatively different behaviour.

2.2.1 Calibration

This section outlines the set of parameter values used to generate the impulse response functions analysed below. This is a starting calibration only and, as such, limited attention is given to its justification. Given the size of the model, there is considerable theoretical freedom over what values the parameters could take. In Chapters 5 and 7 the model parameters are jointly estimated to minimise the Indirect Inference Wald statistic, and that estimated parameter set will replace the calibration outlined here. The Indirect Inference estimator, discussed in Chapter 3, is asymptotically equivalent to Full Information Maximum Likelihood. The parameters chosen below must of course be consistent with the logic of the model and with the UK data, to some level of approximation, but beyond that their importance should not be overstated.

Preference parameters are calibrated as follows. The quarterly discount factor, β, is set at 0.97 as in Meenagh et al. (2010). This value may be somewhat low relative to other literature - King et al. (1988) use 0.988 as their baseline, and benchmark priors used for Bayesian model estimation are often higher still (e.g. Chang et al. 2007). However, the value is well within the wide range of empirically estimated discount factors reported in the metastudy of Frederick et al. (2002, Table 1); as that paper makes clear, the empirical consensus on discount rates is not strong. A quarterly factor 0.97 implies an annual discount factor of roughly 0.89, consistent with a 3% quarterly real rate of time preference, or an annual real rate of 12%.[12]

Coefficients of relative risk aversion ρ_1 and ρ_2 are set at 1.0 and 1.2 respectively. An intertemporal elasticity of substitution (IES) $\frac{1}{\rho_1}$ of unity is consistent with the real business cycle literature.[13] Reduced form estimates of the Euler equation point to lower intertemporal elasticity values (Hall, 1988; Yogo, 2004), but more recent empirical work focusing on low frequency consumption data has shown that an IES of one is empirically defensible (Favero, 2005).

Meenagh et al. (2010) set the coefficient of relative risk aversion for leisure, ρ_2, at 1.0; here ρ_2 is calibrated at 1.2 implying a less than unit intertemporal elasticity of substitution in leisure. This calibration implies that the curvature of the utility function in the leisure dimension is more pronounced than for the consumption dimension; the marginal utility of leisure diminishes faster as leisure increases. The fixed preference weight on consumption, θ, is calibrated at 0.5 following Meenagh et al. (2010), implying an equal weight on leisure.

Preference bias for the domestic good, ω, is set at 0.7 after Meenagh et al. (2010, 2012); the foreign equivalent ω^F is set likewise at 0.7, by symmetry. The import demand elasticity σ is set to unity (i.e. the response of imports to a one percent change in the relative price of the

[12] There is a model restriction on the value of $\ln \beta$ that comes from the Euler equation and the RUIP identity. Since r_t is constrained by the movement of the real exchange rate (which in turn is constrained by the terminal condition to ensure that the current account is balanced in the long run; the terminal condition thus constrains Q_t along the whole simulation path), the Euler equation must be consistent with that value of r_t and the long run rate of consumption growth, otherwise the real interest rate is overdetermined. This is ensured by the constant in the Euler equation, made up of $\ln \beta$ plus any constant from the shock process, i.e. $\ln \frac{E_t \gamma_{t+1}}{\gamma_t} = \ln(1+\gamma_\gamma) = \gamma_\gamma$ in the long run. Since the value of γ_γ must be found empirically, this allows some flexibility on the value of β.

[13] Lucas (1990) calibrates the CRRA parameter at 2.0, but writes that it "seems high" given the cross-country interest differentials it implies through the Euler equation.

imported good, Q_t). The sensitivity of export demand to a one percent change in Q_t is $\sigma^F \frac{1}{\omega}$, also set to one, implying that $\sigma^F = 0.7$ (given $\omega = 0.7$). This calibration is consistent with the Marshall-Lerner condition that the sum of the elasticities of imports and exports with respect to the real exchange rate should be greater than one; this condition must be satisfied for the current account deficit to be reduced by a real exchange rate depreciation. The parameter σ is also the elasticity of substitution between the domestic variety of the good C_t^d and the imported variety C_t^f, known as the Armington elasticity (the 'macro' Armington elasticity in Feenstra et al. (2014)). σ^F is the equivalent substitution elasticity in the foreign country. The US estimates obtained by Feenstra et al. (2014) for these elasticities are "in the neighbourhood of unity regardless of sector" (p.34). The chosen values for import and export demand elasticities with respect to a relative price change are also in the region of UK estimates from empirical studies such as Hooper et al. (2000).

On the production side the share of labour in output, α, is calibrated at 0.7, consistent with the UK estimates reported by Gollin (2002). Quarterly capital depreciation is set at 0.0125, implying an annual rate of 5%; this value is used in Meenagh et al. (2010). The capital demand equation is non-linear and must be linearised around the moving steady states of K and Y. The loglinear relationship is, in general terms:

$$\ln K_t = \zeta_1 \ln K_{t-1} + \zeta_2 E_t \ln K_{t+1} + \zeta_3 \ln Y_t - \zeta_4 . r_t \tag{2.85}$$

The presence of ζ (a fixed coefficient in the adjustment cost function) and d (the firm's discount factor) in these coefficients allows some empirical flexibility, though $\zeta_3 = 1 - \zeta_1 - \zeta_2$ is an important constraint to ensure consistency with the long run [14]. Following Meenagh et al. (2010), the baseline calibration is:

$$\ln K_t = 0.51 \ln K_{t-1} + 0.47 E_t \ln K_{t+1} + 0.02 \ln Y_t - 0.25 \ln r_t \tag{2.86}$$

[14] In long run steady state when all temporary shocks have died out, capital and output must be growing at the same rate; since by detrending the shocks we have removed the deterministic growth path here, we require $K = Y$, so that adding back the long run growth path will imply $K(1+g_k)^t = Y(1+g_y)^t$ and $g_k = g_y$, and the long run capital-output ratio is constant. This condition has been imposed by the terminal conditions on the solution - see Appendix - and the capital equation must not contradict it.

The loglinearised balance of payments condition is:

$$\Delta\hat{b}^f_{t+1} = (r^f_t - g)\hat{b}^f_t + \frac{1}{(1+g)}\left(\frac{EX}{\tilde{Y}}.\ln EX_t - \frac{EX}{\tilde{Y}}.\frac{1}{\omega}\ln Q_t - \frac{IM}{\tilde{Y}}\ln IM_t\right) \tag{2.87}$$

This is calibrated from UK post war data averages $(1955-2011)$ with $\frac{M}{Y} = 0.2135$, $\frac{X}{Y} = 0.208$, and the quarterly output growth rate $g = 0.005$. Note that $\hat{b}^f_{t+1} \equiv \frac{b^f_{t+1}}{Y_{t+1}}$, so that net foreign assets is expressed as a ratio to GDP, and the whole equation has been scaled by the sample average of output.[15] The loglinearised market clearing constraint in volume terms is

$$\ln C_t = c' + \frac{\bar{Y}}{\bar{C}}\ln Y_t - \frac{\bar{X}}{\bar{C}}\ln EX_t + \frac{\bar{M}}{\bar{C}}\ln IM_t - \frac{\bar{K}}{\bar{C}}\ln K_t + (1-\delta-\gamma_k)\frac{\bar{K}}{\bar{C}}\ln K_{t-1} - \frac{\bar{G}}{\bar{C}}\ln G_t \tag{2.90}$$

where K_{t-1} is linearised around a point $\tilde{K}_{t-1} = \bar{K}(1+\gamma_K)^{-1}$. The starting calibration of $\frac{Y}{C}$ and $\frac{G}{C}$ is based on UK 1955 to 2011 averages: $\frac{Y}{C} = 1.732$, $\frac{G}{C} = 0.44$. To ensure consistency with these and with the values of $\frac{X}{Y}$ and $\frac{M}{Y}$ used in the balance of payments condition, $\frac{X}{C} = \frac{X}{Y}.\frac{Y}{C} = 0.361$ and $\frac{M}{C} = \frac{M}{Y}.\frac{Y}{C} = 0.369$. The long-run quarterly growth rate of the capital stock is assumed to be $\gamma_k = 0.005$. The assumption of $\frac{K}{Y} = 3$ implies that $\frac{K}{C} = 3.\frac{Y}{C} = 5.196$. Ultimately whether this is a good enough approximation of the true coefficients is an empirical issue.

The parameter c_1 capturing the response of time spent in innovative activities (z_t) to the subsidy rate (s'_t) is more of a challenge to calibrate. As will be argued in Chapter 6, the macro-econometric literature does not offer a strong prior for this relationship in terms either of sign or magnitude. Among studies finding a positive impact, Falk (2006) estimates the impact of government funded business R&D intensity (i.e. as expenditure as a proportion of GDP) on total business R&D intensity, obtaining significant estimates of $0.13-0.17$ in a fixed effects

[15] The BoP condition is scaled by steady state output and loglinearised as follows

$$\frac{\Delta b^f_{t+1}}{\tilde{Y}} - r^f_t.\frac{b^f_t}{\tilde{Y}} = \frac{1}{\tilde{Y}}\frac{p^d_t EX_t}{Q_t} - \frac{1}{\tilde{Y}}IM_t \tag{2.88}$$

Defining $\hat{b}^f_t \equiv \frac{b^f_t}{Y_t}$ and approximating around a point where $\frac{Y_{t+1}}{\tilde{Y}} = 1+g$ and $\tilde{Q} = \tilde{p}^d = 1$ this becomes

$$(1+g)(\Delta\hat{b}^f_{t+1} - (r^f_t - g)\hat{b}^f_t) = const + \frac{EX}{\tilde{Y}}.\ln EX_t + \frac{EX}{\tilde{Y}}.(\ln p^d_t - \ln Q_t) - \frac{IM}{\tilde{Y}}\ln IM_t \tag{2.89}$$

Using the substitution $\ln p^d_t - \ln Q_t = -\frac{1}{\omega}\ln Q_t$, where we have imposed $\hat{k} = \frac{1-\omega}{\omega}\frac{1}{\rho}\ln\varsigma_t = 0$, gives the BoP constraint shown.

model, though the impact becomes insignificant in the preferred system GMM specification. Westmore (2013), on the other hand, finds a long run elasticity of business R&D expenditure (or the change in the stock) with respect to government funded business R&D of 0.47. Of course, the units of z_t are hours and not R&D expenditure as a proportion of GDP, but R&D expenditure variables might be a reasonable proxy for time invested. However, the lack of identification in the models estimated in this literature suggests we should approach the results with caution. Therefore I use the analytical relationship derived from the first order condition for z_t in the model (equation 2.49 above, repeated here); at a given period of time t, this relationship is a constant. Abstracting from the possibility that it is time-varying allows c_1 to be tied down.[16]

$$c_1 \equiv \frac{dz_t}{ds'_t} = (\frac{\beta\rho_\gamma}{1-\beta\rho_\gamma}\frac{Y_t}{w_t})\frac{1}{(1-s'_t)^2} \tag{2.91}$$

c_1 is positive, reflecting the hypothesis that subsidies enhance incentives to innovation time. Since $\frac{w_t N_t}{Y_t} = \alpha$ in the long run, if $N_t \simeq 0.5$ then $\frac{w_t}{Y_t} = \frac{0.7}{0.5}$ and $\frac{Y_t}{w_t} = 0.714$. Setting s'_t to 0.1416, the average value of the subsidy series over the finite sample period (1981 to 2010), setting the persistence of the unobservable consumption preference error arbitrarily at $\rho_\gamma = 0.5$, and substituting these values into equation 2.91 puts c_1 at 0.912. Evidently this calibration of c_1 is very rough and there is considerable freedom around this parameter, which affects the impact of subsidies on the supply of labour in goods production.[17] The estimation in Chapter 7 will shed further light on its value so I have done limited sensitivity tests here around c_1. The impulse responses in Section 2.2.2 have been generated on the assumption that $c_1 = 0.06$; a lower value is preferred on the basis that z_t is a relatively small proportion of total non-leisure time, and changing its incentives would not be expected to perturb the ordinary labour supply to a large extent, *a priori*. Setting it according to the estimates from Falk (2006) and of Westmore (2013) has no qualitative impact on the IRFs, though of course the labour supply response to a policy shock is magnified.

[16] I assume the marginal impact of s'_t on z_t is the same regardless of the level of s'_t . If $\frac{Y_t}{w_t}$ is constant and all other parameters are also constant, but s'_t clearly exhibits strong trend over time, then c_1 will change with the level of s'_t. However, s'_t is assumed to be a stationary series in the simulation - the trend is removed, so that it has some long run value. This allows the assumption of a constant c_1.

[17] Assuming $\rho_\gamma = 0.9$ raises it to 6.66, while $\rho_\gamma = 0.1$ yields $c_1 = 0.104$; $\rho_\gamma = 0.01$ implies $c_1 = 0.009$. Assuming different values for N_t will also affect its magnitude.

The starting value of the marginal impact of s'_t on productivity growth, b_1 (2.53), must ensure that we are examining a model in which the policy variable variation causes a 'reasonable' amount of the variation in productivity growth; if not, the model is difficult to distinguish from an exogenous growth model. Therefore we must avoid setting b_1 too low - but how low is too low? Estimates in the literature for the impact of R&D subsidies on productivity growth are again variable, depending on the data, model and estimators employed (see Chapter 6). Guellec et al. (2004) find little evidence of an impact of government funded BERD on the growth rate of Multi-Factor Productivity (MFP), though they estimate the response of productivity growth with respect to a unit change in the R&D (stock) intensity at $0.044 - 0.067$; this might roughly correspond to a_1 here (2.42) and b_1 can then be calibrated through the relationship $b_1 = a_1.c_1$. Taking a value in their range for a_1 alongside $c_1 = 0.06$ implies $b_1 \simeq 0.003$. Westmore (2013) also finds government funded BERD has no significant direct effect on MFP growth, though he finds the long run marginal impact of the stock of BERD relative to GDP on MFP growth significant at $0.26 - 0.33$; this together with the estimated 0.47 effect of government subsidies to R&D on BERD itself could imply b_1 between 0.122 and 0.155. Lacking a compelling rationale for choosing among these offerings, b_1 is set in the IRFs at 0.1, implying that a 10 percentage point increase in the proportion of business R&D funded directly by government around its trend results in a 1 percentage point increase in TFP growth in the following period. This value is large enough to distinguish this model from an exogenous growth model, as shown through the variance decomposition in Chapter 7.

The calibration is summarised in Table 2.2.1. C_t^{d*}, C_t^{f*} stand for foreign demand for the domestic good and foreign demand for foreign-produced good, respectively.

2.2.2 Impulse Response Functions for a policy shock

Figures 2.1 to 2.3 show the difference between the base run of the model and the simulated solution after a one-off positive shock to the subsidy rate in the first simulation period. The base run is the solution to the model in the absence of shocks (this solution replicates the original data). The plots show how a particular controlled shock changes the model's behaviour in the simulation relative to the base run.

A full set of impulse response functions (IRFs) for every shock in the model has been

Parameter Assignments		
α	Labour share in output	0.7
β	Quarterly discount factor	0.97
δ	Quarterly depreciation rate	0.0125
ρ_1	CRRA coefficient (C_t)	1.0
ρ_2	CRRA coefficient (x_t)	1.2
θ	Preference weight on C_t	0.5
ω	Home bias in consumption	0.7
ω^F	Foreign equivalent of ω	0.7
$-\sigma$	Import demand elasticity	-1.0
σ^F	Elasticity of substitution (C_t^{d*}, C_t^{f*})	0.7
ζ_1,ζ_2,ζ_3,ζ_4	Capital equation coefficients	0.51, 0.47, 0.02, 0.25
c_1	$\frac{\partial z_t}{\partial s_t'}$	0.06
b_1	$\frac{\partial [d \ln A_{t+1}]}{\partial s_t'}$	0.1

obtained but I limit the discussion here to the dynamic effects of a change in the subsidy rate, since that is the focus of this thesis. The effects are qualitatively similar to an independent productivity shock, except for the additional response of labour to a change in incentives to z_t.

The impulse is a 10% increase in the subsidy rate s', measured as the proportion of BERD funded directly by government.[18] Since the detrended shock process is highly persistent with an AR(1) coefficient of 0.97, the one-off shock has a long-lasting effect on the productivity level, resulting in a productivity growth episode that lasts over 40 quarters (Figure 2.1). There is a negative response in labour supply initially, as the lower opportunity cost of z makes labour a relatively less attractive way to earn. In the initial period, output falls because of this drop in labour, but as higher innovation in period 1 causes higher productivity in period 2, output rises steeply from $t = 2$. Over the simulation period, the real consumer wage rises to offset the income effect on labour supply from the productivity increase, but the resulting substitution effect does not dominate. Output and the real wage are still growing after 40 quarters, while labour continues to fall; eventually Y and w will converge to higher levels, while labour converges to a permanently lower level than the base run. This growth in productivity triggers a real business cycle upswing. Figure 2.2 depicts the strong responses of consumption and capital demand to the growth in A. Adjustment costs in capital prevent investment from overshooting

[18] A large shock is preferred, to make the units of endogenous variable responses easier to read on the graphs.

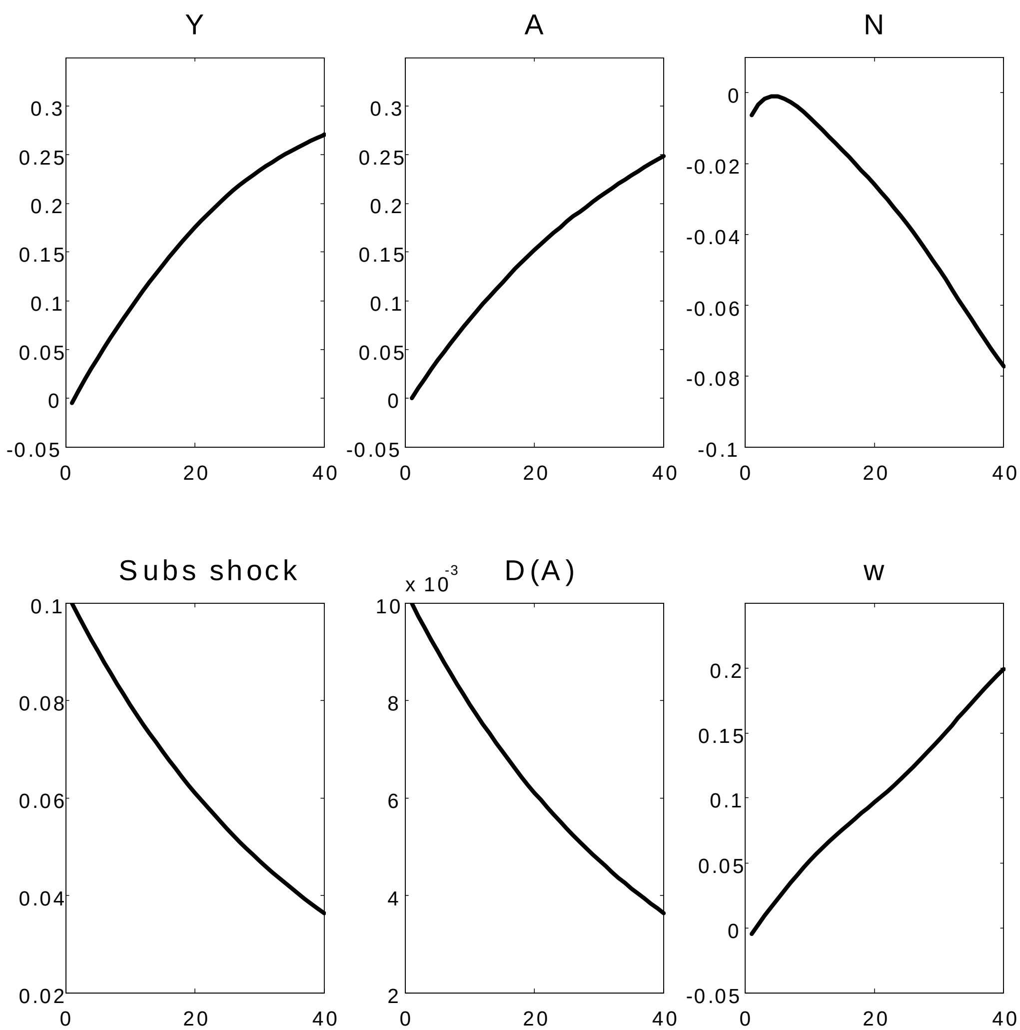

Figure 2-1: Growth episode following a 10% R&D subsidy shock.

in response to anticipated productivity increases. Consumption in the initial period is lower than in the base run because of intertemporal substitution between N and z, the decision to sacrifice the labour wage at $t = 1$ for higher consumption possibilities from the next period onwards. Permanent income rises from $t = 2$, as the real wage and the unit cost of labour to the firm ($w\ hat$) increase steeply towards a higher long run level, so that consumption increases.

The upswing in domestic demand causes the real interest rate to rise, and in this model a higher real interest rate must be matched by an expected real exchange rate depreciation for real uncovered interest parity (Figure 2.3). Recalling that the variable Q is the inverse of the real exchange rate, reflecting the competitiveness of exports, the figure shows that the productivity increase triggers an instant depreciation of the real exchange rate that continues over the whole 40 quarter simulation period. A lower real exchange rate is required to bring world demand for the domestic good into line with supply, since not all extra supply resulting from higher domestic productivity is demanded on domestic markets. With higher permanent income we would expect higher domestic demand for imports, but the real exchange rate depreciation is significant enough to dominate this income effect as the relative price of the foreign good rises. Import demand rebounds after 25 quarters as the real exchange rate converges to its new long run (lower) level. Since Q is still moving after 40 quarters, the domestic real interest rate has not quite converged to zero, though it will in the longer run when the subsidy shock has completely died out and Q reaches its new steady state level. Net foreign assets accumulate throughout most of the simulation period due to the increase in net exports on current account, though converging back to zero by the end of the simulation as imports rebound. The transversality condition ensures that net foreign assets stabilise by the end of the simulation.

2.3 Conclusion

This chapter has laid out the model used in empirical work in Chapters 5 and 7, and its properties have been analysed through the impulse response functions from a one-off policy shock. This model is a standard workhorse in terms of expected macroeconomic and open economy reactions and therefore highly suitable for testing whether productivity is affected by a particular policy variable whose presence is controversial. Since the model has been seen to fit

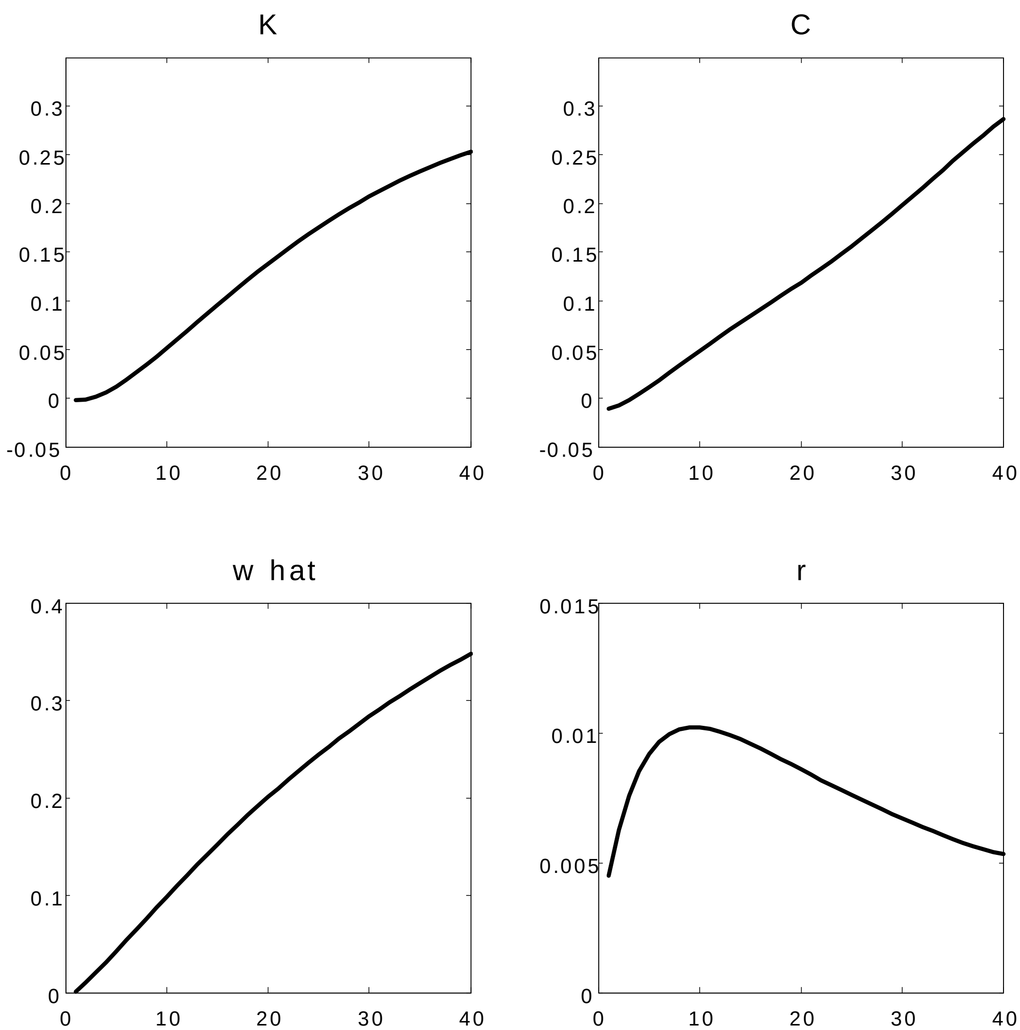

Figure 2-2: Real Business Cycle upswing following a 10% R&D subsidy shock

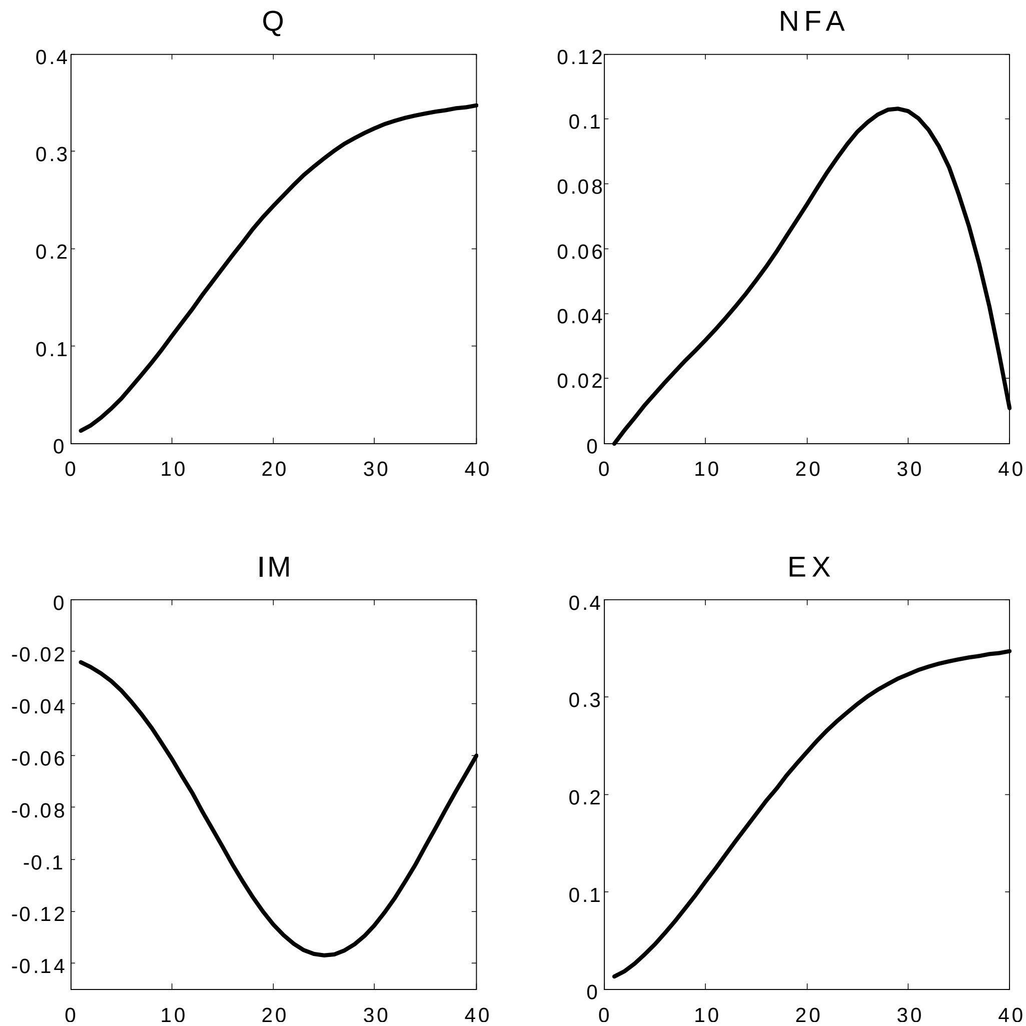

Figure 2-3: Response of Terms of Trade, Net Foreign Assets, Imports and Exports to 10% subsidy shock

the facts in similar tests (Meenagh et al., 2010), the introduction of the policy variable should test whether this policy hypothesis alone has caused the rejection.

Annex 1

More on the consumer choice of z_t

The expected effect of dz_t on the firm's profit function at $t+1$ (and for any $t+i$) is as follows:

$$\frac{d\pi_{t+1}}{dz_t} = \frac{\partial Y_{t+1}}{\partial A_{t+1}}\frac{dA_{t+1}}{dz_t} + \frac{\partial Y_{t+1}}{\partial K_{t+1}}.\frac{dK_{t+1}}{dz_t} + \frac{\partial Y_{t+1}}{\partial N_{t+1}}.\frac{dN_{t+1}}{dz_t} - \frac{dK_{t+1}}{dz_t}(r_{t+1} + \delta + \kappa_{t+1} + \tilde{a}_{t+1}) - \frac{dN_{t+1}}{dz_t}(\tilde{w}_{t+1} + \chi_{t+1}) \quad (2.92)$$

This is to say that dz_t will enhance output directly through its effect on productivity (holding inputs fixed), and will also induce the firm to hire more capital in order to exploit its higher marginal product (similarly for labour). Decomposing the relation further,

$$\frac{d\pi_{t+i}}{dz_t} = \frac{\partial Y_{t+1}}{\partial A_{t+1}}\frac{dA_{t+1}}{dz_t} + (MPK + \Delta MPK).\frac{dK_{t+1}}{dz_t} + (MPN + \Delta MPN).\frac{dN_{t+1}}{dz_t} - \frac{dK_{t+1}}{dz_t}(r_{t+1} + \delta + \kappa_{t+1} + \tilde{a}_{t+1}) - \frac{dN_{t+1}}{dz_t}(\tilde{w}_{t+1} + \chi_{t+1}) \quad (2.93)$$

where MPK signifies the expected marginal product of capital (gross of depreciation and adjustment costs) for $t+1$ *without* the marginal increase in z_t, and ΔMPK is the expected increase in the marginal product accounting for the impact that dz_t would have on TFP. From the firm first order conditions in equations 2.31 and 2.32 (its decisions on the assumption of no change in z_t), the gross marginal products satisfy $MPN = \tilde{w}_{t+1} + \chi_{t+1}$ and $MPK = r_{t+1} + \kappa_{t+1} + \delta + \tilde{a}_{t+1}$ when $dz_t = 0$. Since prices are unaffected by the choices of the representative firm and agent, terms cancel and the relationship reduces to

$$\frac{d\pi_{t+1}}{dz_t} = \frac{\partial Y_{t+1}}{\partial A_{t+1}}\frac{dA_{t+1}}{dz_t} + \Delta MPK.\frac{dK_{t+1}}{dz_t} + \Delta MPN.\frac{dN_{t+1}}{dz_t} \quad (2.94)$$

I assume that the effect of dz_t on the future dividend ($d_{t+i} = \pi_{t+i}$) is simply its direct effect through higher TFP, on the basis that the second and third terms above - the effects on the firm's input demands - are second order and can be ignored. Therefore the expected change in the dividend stream is based on forecasts for choice variables (set on other first order conditions) that are assumed to be independent of the agent's own activities in context of price forecasts; she anticipates only the effect of z_t on the level of output that can be produced with given inputs from $t+1$ onwards.

Of course, in general equilibrium under perfect competition there are zero profits and so after a small change in z there will be zero dividend income (just as before the marginal increase in z). However, the future real wage will rise as a result of the productivity increase and this in practice is how the extra income will enter the agent's budget constraint. From the perspective of the f.o.c. for z at t, this is not an important distinction.

To summarise, the contemporaneous effect of a marginal increase in z_t on the expected dividend occurs via an increase in productivity at $t+1$

$$E_t \frac{d\ d_{t+1}}{dz_t} = E_t \frac{d\pi_{t+1}}{dz_t} = \frac{\partial Y_{t+1}}{\partial A_{t+1}} \frac{dA_{t+1}}{dz_t} \tag{2.95}$$

Since $\frac{\partial Y_{t+i}}{\partial A_{t+i}} = \frac{Y_{t+i}}{A_{t+i}}$ (reiterating the assumption above that second order effects on firm demand for capital and labour can be ignored) the impact of z_t on dividends at a future period $t+i$ is:

$$\frac{dd_{t+i}}{dz_t} = \frac{Y_{t+i}}{A_{t+i}} \frac{dA_{t+i}}{dz_t} > 0,\ i \geq 1$$

Note that there is no associated uncertainty about the impact of innovative activity on future productivity and hence permanent income, except insofar as the rational agent is aware that future output is subject to several different types of shock.

Chapter 3

Methodology: Indirect Inference Testing and Estimation Procedure

In this chapter I present the Indirect Inference Wald testing methodology applied to the policy-driven growth hypotheses investigated in chapters 5 and 7, and the estimation procedure used to find the calibration of each distinct model that minimises the distance of the simulated from actual data.

3.1 Indirect Inference

The traditional approach to evaluating calibrated real business cycle (RBC) models is to calculate the moments of the model's simulated data series and compare those, singly and informally, to the moments of the observed data series. The goal is to see where the model fails to replicate certain stylized facts; see Kydland and Prescott (1982, pp.1364-65); also Kydland and Prescott (1991) and Chari et al. (2002, pp. 549-50). Indirect inference essentially follows the same strategy, extending it to a formal statistical comparison of the joint behaviour of the variables as summarised by an auxiliary model estimated on simulated and observed data. Le et al. (2010, 2011) point out that basing the evaluation on the closeness of individual time series moments one by one can lead to erroneous conclusions, as the model's simultaneous implications for cross-moments are neglected. Since DSGE models frequently imply restrictions on the joint moments, these must also be examined to see whether the data and the model simulations are ‘close’.[1]

Here an auxiliary model acts as a descriptor of the joint features of the data (both observed and simulated). The bootstrapping procedure generates a large number of pseudo-datasets, each of which provides a set of estimated coefficients for the auxiliary model. Hence the sampling distribution of the auxiliary model coefficients is generated and we can see whether the set of coefficient estimates from the observed data sample lies within that model-based distribution, for a given rejection region. Following Le et al. (2011, 2014), amongst others, I use a Wald statistic based on the distance between the auxiliary model parameters estimated on simulated data and the parameters estimated on observed data. This is a formal evaluation criterion for the model.

Therefore I am to some extent "tak[ing] the model seriously as a data-generating process" in confronting it with the data, rather than adopting the ’calibrationist’ stance, according to which a DSGE model "should not be regarded as a null hypothesis to be statistically tested" (Canova, 1994, p. S124; cf. Prescott 1991, p.5). According to the latter view, DSGE models are inherently ’false’ and their predictions are compared with stylized facts solely to diagnose where theories need to be modified; though it is not clear how falseness is conceptualised in this process, nor precisely where the line is drawn between success and failure for the model.

Drawing repeatedly from assumed asymptotic distributions to obtain new sets of shocks is not justified when we do not know what these distributions are[2]. Instead we use the sample residuals themselves as the available data on the distribution, and bootstrap the innovations in those to obtain the distribution closest to the one generating the data. That is, the structural model equations - in conjunction with the observed data and a particular coefficient set -

[1] e.g. in a model with a Fisher equation, one expects the persistence in inflation to be highly positively correlated with persistence in interest rates. Finding that the model can ’match’ the persistence of inflation in the data and, separately, the persistence of the interest rate in the data, is therefore not a sufficient test of the model; we would like to know if it can match the correlation of those persistence measures at the same time. Taking the single estimates for each persistence parameter alone and finding them acceptably close to the data, hence concluding in favour of the model, is equivalent to conducting a joint test on a diagonalised covariance matrix. However, if the covariance matrix generated by the model is in fact non-diagonal, this implies a different joint distribution which could lead to a rejection of the estimates for the two persistence parameters when those estimates are considered together (see Le et al. 2011, pp. 2082-3, Note 4 and Figure 1).

[2] Assuming shocks follow asymptotic distributions could lead to bias in the estimation of the auxiliary model coefficients when they come from near unit-root processes, hence distorting the test; see references given in Le et al. (2011) e.g. Horowitz, 2001a,b

imply certain 'structural' residuals in order to hold with equality.[3] These are in turn modelled as autoregressive processes, some stationary and one non-stationary (see Chapter 2, Section 2.1.7), depending on identically independently distributed (i.i.d.) innovations. Given the assumed (calibrated or estimated) form for the structural error processes, these i.i.d. innovations are obtained as residuals. The bootstrapping procedure then involves drawing randomly with replacement from the set of innovations and using these pseudo-random shocks to generate simulated datasets under the null hypothesis that the model is true. The small-sample properties of the bootstrap are checked by numerical methods in Le et al. (2011) and found reliable; Monte Carlo experiments show only small inaccuracies in the size of the test in small samples. Le et al. (2011) also show the consistency of the Wald statistic, so that the bootstrap distribution converges on the true chi-squared distribution as the sample size increases.

The full indirect inference testing procedure is formally outlined elsewhere; the reader is referred to Minford et al. (2009), Le et al. (2011), and to Meenagh et al. (2012) and Le et al. (2014) for the application to non-stationary data. Here the steps are given in brief:

1. Using calibrated parameter set (θ), generate J bootstrap simulations from the DSGE model.[4]

2. Add back the effects of deterministic trends removed from shocks, and estimate the auxiliary model on all J pseudo-samples.

3. The resulting coefficient vectors a_j ($j = 1, ..., J$) yield the variance-covariance matrix Ω of the DSGE model's implied distribution for these coefficients. Hence the small-sample distribution for the Wald statistic $WS(\theta)$ is obtained:

$$WS(\theta) = (a_j - \overline{a_j(\theta)})' W(\theta)(a_j - \overline{a_j(\theta)})$$

$\overline{a_j(\theta)}$ is the arithmetic mean of the J estimated vectors and $W(\theta) = \Omega(\theta)^{-1}$ is the inverse of the estimated variance-covariance matrix. So the Wald statistic utilises the first and

[3] Where expectations enter on the right hand side of structural equations they are are estimated using a LIML procedure due to (McCallum (1976) and Wickens(1982)).

[4] In the empirical work carried out in Chapters 5 and 7, the number of bootstrap simulations has been set to $J = 1000$.

second moments and cross-moments of the distribution of the auxiliary model coefficients that describe the data generated by the model.

4. Find the test statistic, $WS^*(\theta)$

$$WS^*(\theta) = (\hat{\alpha} - \overline{a_j(\theta)})' W(\theta)(\hat{\alpha} - \overline{a_j(\theta)})$$

a function of the distance between $\overline{a_j(\theta)}$ and $\hat{\alpha}$, where $\hat{\alpha}$ is the coefficient vector estimated from the UK data. Then see where this test statistic falls within the model-generated distribution.

Inference can proceed by comparing the percentile of the Wald distribution at which the critical Wald statistic falls with the chosen size of the test; for a 5% significance level, a percentile above 95% would fall into the rejection region. Alternatively we can present the same information as a p-value[5] or a t-statistic, obtained from the square root of the Wald, also known as the Mahalanobis distance.[6] This is a useful indicator of how far the Wald from the data lies in the tail of the distribution. Thus indirect inference tests the ability of the model to generate simulated data with properties (as evaluated by the auxiliary model) that are statistically similar to the properties of observed data, unlike direct inference, which tests the ability of the model to forecast current data ('nowcasting'). Le et al. (2015b) compare the indirect inference testing procedure applied here with a direct likelihood ratio based test (as usually applied) using a Monte Carlo experimental strategy; they find that the power of the Indirect test here is substantial in small samples while that of the usual Likelihood Ratio test is relatively weak. The finding holds whether stationarised or non-stationary data are used to simulate the model. Therefore we can be confident that false models will be rejected by this Indirect Inference

[5] This is [100 minus the Wald percentile]/100 .

[6] Since the Wald is a chi-squared, the square root is asymptotically a normal variable. Applying a small sample correction, the formula is

$$MD\_Norm = \left(\frac{\sqrt{2WS^*(\theta)} - \sqrt{2k}}{\sqrt{2WS^{95}} - \sqrt{2k}} \right) * 1.645$$

where k is the length of $\hat{\alpha}$ (the vector of auxiliary model parameters estimated on the observed data), and WS^{95} is the value of the Wald statistic falling at the 95th percentile of the bootstrap distribution. This is scaled by 1.645 so that when $WS^*(\theta) = WS^{95}$ the statistic corresponds to the 95th percentile of the standard normal distribution.

test in empirical work. Applications of the test in the macroeconomic literature include Le et al. (2010), who test a two-country DSGE model with some nominal rigidity calibrated to the EU and US for 1975-2000; Le et al. (2011), who test the New Keynesian model of the US economy along the lines of Christiano, Eichenbaum and Evans (2005), calibrated according to the Bayesian estimates of Smets and Wouters (2007), for the post-war era as well as various sub-periods; and an application to a calibrated model of the UK using stationarised data by Minford et al. (2009). Le et al. (2014) test a model of macroeonomic crisis in China with non-stationary data. In my study I apply the Indirect Inference methodology for the first time to a semi-endogenous growth model of the UK, using non-stationary data.

What is the virtue of testing the policy hypothesis in a DSGE model, as opposed to other methods? For an unrestricted VAR - the tool of macroeconomic analysis advocated by Sims (1980) - there are many different time series models (different in terms of lag structure and included variables) that can adequately describe the behaviour of the variables of interest, and it is not clear which should be preferred or how the results should be interpreted (see Wickens, 2015 for more on this point). Likewise, it has been argued above that the panel approach taken in much of the empirical growth literature cannot control adequately for regressor endogeneity; in fact the models that are estimated suffer in general from a lack of identification, in that the parameter estimates uncovered could be generated from multiple different theories. Since the results therefore do not necessarily distinguish one causal mechanism from another, it is not clear what conclusions can be drawn in terms of growth policy effectiveness. This applies both to the estimation results, and to any statistical tests carried out on those results; one is simply not sure what theory is being tested.

The rational expectations DSGE modelling approach used here has the advantage of being an identified test of a particular causal explanation of growth. That is, the DSGE model being tested has a distinct reduced form that in turn could not have been generated by a different structural model. In this case we want to rule out other models with a different causal mechanism; particularly one in which policy responds to growth rather than the other way round. Identification is ensured in this model by the rational expectations variables which imply over-identifying restrictions on its reduced form representation, approximated here by the auxiliary model[7]. Unrestricted estimates of the auxiliary model coefficients on model-generated data will therefore reflect the restrictions imposed by this particular model and no other; comparison to the unrestricted estimates of the auxiliary model on the observed data serves as a test of this particular theory.

The policy shock is bootstrapped separately from other shocks since the identifying assumption is that it is uncorrelated with other sources of the general 'productivity shock'. All other shocks are bootstrapped by time vector so as to preserve potential time correlations.

The Indirect Inference test is the basis for the Indirect Inference estimation carried out in Chapters 5 and 7 for the different growth models under investigation. The estimation procedure involves searching over the parameter space, within certain bounds, to find the vector of structural coefficients, θ, which minimises the Wald statistic given the chosen auxiliary model and the sample data. This idea of optimal calibration, whereby the model is simulated for different values of its coefficients and the simulated behaviour in each case is used to construct a test statistic on which to judge its closeness to the observed data, has been in circulation for some time. Smith (1993) uses such a method to estimate a dynamic real business cycle model; see also Canova (1994, 2005) and further references given in Le et al. (2011).[8]

In Chapters 5 and 7, a 'simulated annealing' algorithm is employed to perform the indirect inference Wald test for 1000 points in the parameter space, logging the relevant test statistics for each. I have searched within 30% bounds of the initial calibration, for selected parameters; these are generally preference-related parameters, as well as the policy-growth parameter, for which no strong priors exist. The same auxiliary model is used throughout.

[7] Le et al. (2014) propose a numerical method to check the identification of rational expectations DSGE models, and show identification for two widely used models. The model used in Chapter 2 has been checked for identification using this test. Note that the instance of an unidentified Rational Expectations DSGE model discussed in Canova and Sala (2009) is a special case and not the rule for this class of models.

[8] Le et al. (2011) find that the small sample bias associated with the indirect estimation procedure used here is far lower than than of full information maximum likelihood, with a mean bias of c. 4% (this is about half the bias of FIML).

3.2 Choice of auxiliary model

We know that the solution to a log-linearised rational expectations DSGE model takes the form of a restricted VARMA, or approximately a VAR, where the expectations will in general provide overidentifying restrictions on the coefficients to ensure the model's identification. These restrictions should be implicit when an unrestricted VAR is estimated on data generated using the model; comparison to an unrestricted VAR estimated on the observed data should serve as a test of the null hypothesis of the model (given identification). An auxiliary model with stationary errors is required when endogenous variables are non-stationary by virtue of their dependency on non-stationary exogenous variables. Therefore a Vector Error Correction Model is appropriate here. Below it is shown, following Meenagh et al. 2012 and Le et al. (2015a, pp. 11-12), how the chosen auxiliary model is an approximation of the reduced form of the DSGE model under the null hypothesis, and that it can be represented as a cointegrated VARX.

The full log-linearised structural model, comprising a p x 1 vector of endogenous variables y_t, a r x 1 vector of expected future endogenous variables $E_t y_{t+1}$, a q x 1 vector of non-stationary variables x_t and a vector of i.i.d. errors e_t, can be written in the general form

$$A(L)y_t = BE_t y_{t+1} + C(L)x_t + D(L)e_t \tag{3.1}$$

$$\Delta x_t = a(L)\Delta x_{t-1} + d + b(L)z_{t-1} + c(L)\epsilon_t \tag{3.2}$$

x_t is a vector of unit root processes, elements of which may have a systematic dependency on the lag of z_t , itself a stationary exogenous variable (this variable is dropped in the rest of the exposition, we can subsume it into the shock). ϵ_t is an i.i.d., zero mean error vector. All polynomials in the lag operator have roots outside the unit circle. Since y_t is linearly dependent on x_t it is also non-stationary. The general solution to this system is of the form

$$y_t = G(L)y_{t-1} + H(L)x_t + f + M(L)e_t + N(L)\epsilon_t \tag{3.3}$$

where f is a vector of constants. Under the null hypothesis of the model, the equilbrium solution for the endogenous variables is the set of cointegrating relationships (where Π is p x p)[9]:

$$
\begin{aligned}
y_t &= [I - G(1)]^{-1}[H(1)x_t + f] && (3.4)\\
&= \Pi x_t + g && (3.5)
\end{aligned}
$$

though in the short run y_t is also a function of deviations from this equilbrium (the error correction term η_t):

$$y_t - (\Pi x_t + g) = \eta_t \tag{3.6}$$

In the long run, the level of the endogenous variables is a function of the level of the unit root variables, which are in turn functions of all past shocks.

$$
\begin{aligned}
\bar{y}_t &= \Pi \bar{x}_t + g && (3.7)\\
\bar{x}_t &= [1 - a(1)]^{-1}[dt + c(1)\xi_t] && (3.8)\\
\xi_t &= \Sigma_{s=0}^{t-1} \varepsilon_{t-s} && (3.9)
\end{aligned}
$$

Hence the long-run behaviour of $\bar{x}_t$ can be decomposed into a deterministic trend part $\bar{x}_t^D = [1 - a(1)]^{-1}dt$ and a stochastic part $\bar{x}_t^S = [1 - a(1)]^{-1}c(1)\xi_t$, and the long run behaviour of the endogenous variables is dependent on both parts. Hence the endogenous variables consist of this trend and of deviations from it; one could therefore write the solution as this trend plus a VARMA in deviations from it. An alternative formulation is as a cointegrated VECM with a mixed moving average error term

$$
\begin{aligned}
\Delta y_t &= -[I - G(1)](y_{t-1} - \Pi x_{t-1}) + P(L)\Delta y_{t-1} + Q(L)\Delta x_t + f + \omega_t && (3.10)\\
\omega_t &= M(L)e_t + N(L)\varepsilon_t && (3.11)
\end{aligned}
$$

which can be approximated as

$$\Delta y_t = -K[y_{t-1} - \Pi x_{t-1}] + R(L)\Delta y_{t-1} + S(L)\Delta x_t + h + \zeta_t \tag{3.12}$$

[9] In fact the matrix Π is found when we solve for the terminal conditions on the model, which constrain the expectations to be consistent with the structural model's long run equilibrium.

or equivalently, since $\bar{y}_{t-1} - \Pi\bar{x}_{t-1} - g = 0$,

$$\Delta y_t = -K[(y_{t-1} - \bar{y}_{t-1}) - \Pi(x_{t-1} - \bar{x}_{t-1})] + R(L)\Delta y_{t-1} + S(L)\Delta x_t + m + \zeta_t \tag{3.13}$$

considering ζ_t to be i.i.d. with zero mean. Rewriting equation 3.12 as a levels VARX(1) we get

$$y_t = [I - K]y_{t-1} + K\Pi x_{t-1} + n + \phi t + q_t \tag{3.14}$$

where the error q_t now contains the suppressed lagged difference regressors, and the time trend is included to pick up the deterministic trend in $\bar{x}_t$ which affects both the endogenous and exogenous variables. x_{t-1} contains unit root variables which must be present to control for the impact of past shocks on the long run path of both x and y. This VARX(1) approximation to the reduced form of the model is the basis for the unrestricted auxiliary model used throughout the estimation in Chapters 5 and 7.

Following Le et al. (2011, 2015a) I use a 'Directed Wald' statistic to evaluate the model, rather than the full Wald criterion which would include all the endogenous variables in the auxiliary model (there are in fact nine non-stationary endogenous variables in the model for which we would expect a long-run cointegrating relationship to hold). Strictly speaking, the full Wald would also be based on estimation of a higher order VARX, as this would be a more faithful representation of the structural model's reduced form solution. However, the power of the full Wald test increases as more endogenous variables are added and as the lag order is raised, leading to uniform rejections (Le et al. 2015b). The Directed Wald involves selecting certain endogenous variables viewed as key for evaluating the theory being tested. In this case, the focus is on the growth hypothesis and on the behaviour of output and productivity, conditional on the lagged policy variable. The use of the Directed Wald can be seen as a nod towards the inherent 'falseness' of DSGE models (not merely at the level of their assumptions but also in their ability to match the macroeconomic data). We note that there is some misspecification in the model which prevents it from being the 'true' DGP for the historical data; it imposes many restrictions on the reduced form description of the data, some of which are not valid. Nevertheless, the model serves as an internally consistent backdrop for us to examine, with statistical formality, the causally identified theory that policy drives the behaviour of productivity and hence output.

The test is whether the model replicates the features not just of output and productivity taken singly, but the joint behaviour of those variables, conditional on the behaviour of any non-stationary predetermined variables and of the policy variable. The chosen auxiliary model ensures that the model is evaluated on this joint criterion.

The VARX(1) in equation 3.15 serves as the auxiliary model used in the empirical work presented in Chapters 3 and 4, being a parsimonious description of some key features of the model.[10]

$$\begin{bmatrix} Y_t \\ A_t \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \begin{bmatrix} Y_{t-1} \\ A_{t-1} \end{bmatrix} + \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \end{bmatrix} \begin{bmatrix} b^f_{t-1} \\ \tau_{t-1} \\ t \\ c \end{bmatrix} + \begin{bmatrix} e_{1t} \\ e_{2t} \end{bmatrix} \tag{3.15}$$

The coefficient vector a_j used to construct the Wald distribution includes OLS estimates of b_{11}, b_{12}, b_{21}, b_{22}, $c_{11,}$ c_{12}, c_{21}, c_{22}, and the variances of the fitted stationary errors e_{1t} and e_{2t}; the same coefficients make up vector $\hat{\alpha}$ estimated on the observed data. Therefore this is a test of whether the model can replicate the data features of output and productivity jointly, in terms of their persistence as well as their variances and covariances. The errors are tested for stationarity using the Augmented Dickey-Fuller test. These are included in the test so that the volatility as well as the interrelations of the variables can be captured. The trend term in the VARX(1) captures the deterministic trend in the data and in the simulations. Since the focus of the study is on the stochastic trend resulting from the shocks, the deterministic trend is not part of the Wald test on which the model's performance is evaluated.

Productivity, measured as the Solow residual given the model's calibrated production function, is a key variable in the regression to provide cointegration under the null hypothesis of the model, being a non-stationary variable on which the non-stationary endogenous variables depend. The productivity variable enters the VARX as an endogenous variable, since it has been modelled as a function of the policy variable which has been treated as exogenous and

[10] In practice the power of the test remains strong for different reduced form approximations; Le et al. (2015) look at the small sample properties of Indirect Inference with various auxiliary models; they find that for small samples, although a VARX(1) is a severe approximation the power of the test to reject a false null remains strong.

trend stationary. The restrictions implied by the DSGE model on this auxiliary model would impose $b_{21} = 0$ and $b_{22} = 1$, the hypothesis being that productivity drives output and not that lagged output sets current productivity. However, the auxiliary model is left unrestricted. Alternative structural models may predict reverse causation or feedback and the auxiliary model should describe the data in an unprejudicial manner, so we leave it free to express the presence of feedback if this is found in the data; we would expect the Wald test to reject the model if its restrictions are strongly violated. Like productivity, lagged net foreign assets, b^f_{t-1}, is a driving variable of the system. Given that its unit root preserves the effects of all past current account imbalances, its stochastic movements affect the long run solution path of the endogenous variables; it must therefore be included in the regression to guarantee cointegration. That is, like x_{t-1} in the general explanation above, it controls for the stochastic trend in the long run level of $\bar{x}_t$ and hence $\bar{y}_t$. This is the extent to which the structural model is imposed on the auxiliary model - we use it to derive what we think is a cointegrated VARX (provided the model holds in its assumptions around the unit root processes), and then we test that VARX for the stationarity of its residuals.[11] We know that OLS is a biased estimator of the auxiliary model due to the presence of lagged endogenous variables as regressors, so no emphasis is placed on the magnitudes of the estimated coefficients. The relevant question is whether the bias of the auxiliary model estimation procedure affects the properties of the test. Since the same auxiliary model and estimator is used for the description of the simulated data and the observed data, the same bias applies for both; hence the power of the test should not be affected. In other words, we ask whether the model-implied OLS-estimated-VAR would generate the same OLS-estimated-VAR as the actual data. Monte Carlo experiments confirm that the power is high (Le et al. 2011, p.2101).

3.3 Conclusion

This chapter has outlined the Indirect Inference testing and estimation methodology applied in the empirical work presented in this thesis. In Chapters 5 and 7, I first give results for an

[11] Also imposed is the measurement of the productivity variable, which is the Solow residual backed out from the calibrated Cobb-Douglas production function on the assumption of fixed input shares and constant returns to scale. Since these assumptions are made for both the observed data and the simulated data, the test should not lose power if the production function is misspecified.

Indirect Inference test of the model given the starting calibration, and then go on to estimate the model parameters using Indirect Inference estimation.

Chapter 4

Policy-driven Growth via Entrepreneurs: Motivation and Literature Review

4.1 Introduction

> "It is deeply embedded in the current European policy approach that the creativity and independence of the self-employed contribute to higher levels of economic activity." Carree et al. (2002, p.284).

> "…the revolutionary breakthroughs continue to come predominantly from small entrepreneurial enterprises, with large industry providing streams of incremental improvements that also add up to major contributions." Baumol (2004, p.9).

> "Entrepreneurial activities can be expected to decrease under higher regulations, administrative barriers and governmental intervention in the market." Acs et al. (2009, p.22)

Entrepreneurship has been high on the policy agenda for growth across OECD countries for over a decade, though the importance of an entrepreneurial growth channel is empirically less than certain: "everybody wants entrepreneurship, even if the link to growth is not clear" (OECD, 2006, p.3).

The UK coalition government elected in 2010 has strongly endorsed entrepreneurship as an element of its ‘Growth Strategy’. Its Plan for Growth (HM Treasury, 2011) consists of four “overarching ambitions” in the pursuit of economic growth, the first being “to create the most competitive tax system in the G20”, and the second “to make the UK one of the best places in Europe to start, finance and grow a business” (p.5). The third and fourth are, respectively, to stimulate investment and exports, and to “create a more educated workforce that is the most flexible in Europe”. Note that human capital accumulation is last on this list and that even then, the fourth point conflates two workforce objectives: skill accumulation and labour market flexibility. This last is to be achieved by ensuring that the UK has the “Lowest burdens from employment regulation in the EU”, while the business environment is to be improved by achieving “A lower domestic regulatory burden,” amongst other policies (p.6).

This is strong testimony, therefore, to a prevalent belief among UK policymakers that policy drives economic growth, in particular tax and regulatory policy, as these are thought to be “barriers to entrepreneurship”.[1] Indeed, since the World Bank began systematically to rank countries according to Ease of Doing Business, a deregulatory trend has gathered pace across the OECD; see Figures 4.2 and 4.3 below. The UK was an early starter among OECD countries in the deregulation of labour and product markets (Figure 4.3; Tables 4.2 and 4.3), and this has been credited in part with reversing the trend in UK relative economic decline through its stimulating effects on competition and productivity (Crafts, 2012; Card and Freeman, 2004). One objective in this thesis is to see whether this credit is duly given.

The impact of taxation on growth via business activity is also a focus of this study. Taxes may distort investment decisions and hence macroeconomic performance, and this logic led to sharp cuts in both personal and corporate income tax rates from the early 1980s in the UK as part of a broader programme of supply side policy reforms. However, Baliamoune-Lutz and Garello (2014) note that, “If in the past some OECD governments have emphasized the link between tax cuts and entrepreneurship as the basis for their tax cut policies (for example during the Reagan and Thatcher administrations in the 1980s), most large European Union

[1] The OECD endorsed the characterisation of regulation as a barrier to entrepreneurship. See for example OECD (2015), Figure 25, a graph entitled “There is scope to reduce barriers to entrepreneurship” which plots the UK Product Market Regulation (PMR) scores against the average of the ‘best’ five OECD countries in terms of freedom from PMR.

countries today have bad rankings in terms of tax rates and tax regulations." As measured by the World Economic Forum's 2010-2011 Global Competitiveness Report (GCR), a survey-based measure of perceptions, tax rates were judged the most "problematic factor for doing business" in the UK, marginally ahead of access to finance and tax regulations, and three times more of a problem than insufficient worker skills.[2]

In the current socio-economic climate, when governments are required to spend without building up excessive sovereign debt, there is a temptation to increase marginal tax rates, particularly at the top of the income distribution; this is also a natural response to the perception of increasing social inequality. The hike in the UK top rate of personal income tax in 2009 is an example of such a policy, which went ahead in spite of independent analysis at the time suggesting that revenues would not rise as a result due to behavioural responses (Brewer and Browne, 2009).

Therefore the demonstration of a relationship from tax rates and tax progressivity to the individual decision margin and hence to productivity growth is of great interest. Would tax rate increases at the top of the income distribution affect the growth rate, or is this essentially rhetoric promoted by vested interest groups who stand to lose from such reforms? This need not imply overt dissembling by lobbyists, since the historical experience may permit such an interpretation when casually viewed. Indeed, this is the issue of identification in action, the problem being that a casual look at the historical evidence permits several alternative explanations of how it was generated. Various models of causation may lead to the reduced form relationship between tax and growth (or regulation and growth) observed in the data.

For this reason it is desirable to derive the relationship from tax and regulatory policy to growth in a structural model, and see in Chapter 5 whether that data generating process as a whole can explain the historical productivity experience in the UK for a particular sample, when appropriate counterfactuals are provided through bootstrapping.

This chapter provides context and an academic literature review to motivate the empirical work presented in Chapter 5. From the point of view of this investigation, most of the studies reviewed here are problematic. Macro-level regression studies suffer from a variety of

[2] These three factors still top the list obstacles to business in the GCR 2014-15, though tax rates are now third on the list, falling from the top spot in 2013-14 perhaps due to reductions in corporate tax rates and R&D tax credit increases implemented in intervening years.

methodological limitations and are rarely identified, making the interpretation of estimated relationships difficult; simulation exercises around the macroeconomic impacts of policy reforms are usually conducted in structural models which are calibrated and rarely tested in any formal sense; and micro-level studies, though often more successful at addressing identification issues, cannot tell us about the macroeconomic impacts of policy. Therefore the following review provides some context for the contribution of this thesis, highlighting some weaknesses in existing evidence on the aggregate relationship between UK policy and economic growth, and the need to test theories in an identified setup where the direction of causation is unambiguous.

4.2 Defining Entrepreneurship

It has been stated that the agent of growth here is the 'entrepreneur', which requires some explanation. A sizable literature is devoted to finding a precise and workable definition of entrepreneurship; if an entrepreneur is defined by his function then this poses problems, since those identified as entrepreneurs in society and in the academic literature have varied functions, not all of which are present in every instance. The plurality of definitions blurs the concept of entrepreneurship and is certainly responsible, in part, for the relative lack of empirical work on its impact on growth; to be empirically 'operationalised' in this context, a definition must map to some measurable phenomenon in the data.

Wennekers and Thurik (1999) gather thirteen roles for the entrepreneur identified in the economics literature: of these some are economic functions (bearer of uncertainty, innovator, allocator of resources, arbitrageur, supplier of financial capital) while others relate to observable behaviour (the owner-manager of a firm, employer of factors of production, one who starts up a new business). Cantillon (1755) is generally credited as the first to identify the entrepreneur, or 'undertaker', as the driver of the market process, transacting under uncertainty. Knight (1921) and later Drucker (1970) also emphasize market decision-making under uncertainty as the defining characteristic of the entrepreneur; the entrepreneur makes choices in an environment in which expectations about the future are subjective, and stands to make losses if his expectations are proved wrong; successful entrepreneurs emerge as those whose expectations were correct. However, entrepreneurship is first singled out as a mechanism for change and economic development in the work of Schumpeter (1911, translated 1934).

The function of Schumpeter's entrepreneur is to innovate, where 'innovation' is "the doing of new things or the doing of things that are already being done in a new way" (Schumpeter, 1947, p.151), and his sphere of operation is the market, since he is motivated by profit. Schumpeter's definition brings out the link between 'entrepreneur' and 'enterprise', the latter in the sense of taking initiative in a market context, and does not therefore tie the entrepreneur either to smallness or necessarily to start-ups. Entrepreneurship can exist in large and/or incumbent businesses as long as the particular venture is new, so it includes the phenomenon of 'intrapreneurship'. Schumpeter also draws an important distinction between invention and entrepreneurship: "The inventor produces ideas, the entrepreneur 'gets things done,' which may but need not embody anything that is scientifically new. Moreover, an idea or scientific principle is not, by itself, of any importance for economic practice." (p.152)

There is, in other words, a difference between general knowledge and economically useful knowledge (cf. Arrow, 1962), and the entrepreneur's role is to transform knowledge into something economically productive. Note that this does not preclude the entrepreneur from being an 'inventor', or creating new knowledge, but that would be in addition to transforming that knowledge into something of commercial value. Schumpeter gives five manifestations of entrepreneurship so-defined (1934, p.66): new (or improved) goods, new production methods, new markets, new supply sources of intermediate goods, and new methods of organisation.

While Schumpeter's 1947 article mentions only the entrepreneur's "creative response" to changing economic circumstances, the assertion being that entrepreneurs are the principal vehicle for this productive creativity in a capitalist market economy, he is most cited in the growth and innovation literature for his theory of creative destruction, a process which "incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating the new one" (1942, Chapter 7, p.82). The "perennial gale" of creative destruction arises out of "capitalist enterprise", which drives progress, while forcing those who do not adapt to exit. We might, therefore, expect creative destruction to show up in the data as high firm turnover, with high entry as well as high exit rates. The concept is intuitively appealing in the context of technological progress - clearly new ways of performing a similar production process build on older technologies, but necessarily replace them in the marketplace, constituting higher quality substitutes rather than complements. This theory has therefore found much attention in more recent literature on endogenous technical change, most notably Aghion and Howitt (1992), on which more below. For now, we note Schumpeter's emphasis on the role of the entrepreneur in the creative process, which in turn is responsible for pushing the productivity frontier outwards, constantly shocking the system out of equilibrium.

Another (here it is argued, complementary) interpretation of entrepreneurship is offered by Kirzner (1973), who defines the entrepreneur as an arbitrageur in a broad sense, one observing and exploiting opportunities for profit that arise out of market disequilibria. "The entrepreneur's activity is essentially competitive" (p. 17): through competition, entrepreneurs eradicate disequilibria and allow markets to allocate resources and welfare optimally. In contrast to Schumpeter's entrepreneur, who pushes the frontier itself forward, Kirzner's entrepreneur pushes aggregate production towards the production possibility frontier. These Schumpeterian and Kirznerian entrepreneurial activities both play a role in raising the average productivity level in the economy, though without the creative responder/destructor there would be no sustained growth.

The entrepreneurial growth channel identified in the present paper excludes neither the creative responder/destructor nor the arbitrageur, since both identify and exploit new opportunities for profit and, in doing so, alter the market environment (Karlsson et al., 2004), the result of which is increased economic activity and higher welfare (via increased consumption and leisure for the household). In both cases, free entry is a requirement for the entrepreneur to affect the economy. Another requirement is the appropriability of the returns that result ~at least enough to cover costs ~since entrepreneurial incentives are otherwise undermined.

In their synthesis of the entrepreneurship literature up to 1999, Wennekers and Thurik (1999) propose this definition:

"Entrepreneurship is the manifest ability and willingness of individuals, on their own, in teams, within and outside existing organizations, to: i) perceive and create new economic opportunities (new products, new production methods, new organizational schemes and new product market combinations) and to ii) introduce their ideas in the market, in the face of uncertainty and other obstacles, by making decisions on location, form and the use of resources and institutions." (p.46-47)

Wennekers and Thurik (henceforth WT) go on to say that "where on the one hand entrepreneurial behavior requires entrepreneurial skills and qualities, it also implies participation in the competitive process on the other." It may be that entrepreneurial skills are human capital that can be accumulated through education, or not. Here we abstract from that channel. Human capital accumulation through education may affect some part of entrepreneurial 'capital', but the focus here is on a part of entrepreneurial activity unrelated to general schooling. This study asks whether entrepreneurship, *as identified by the incentive mechanism in the model*, causes productivity growth.[3] As long as these incentives cannot be interpreted as incentives to human capital accumulation, we can be confident that a separate 'entrepreneurial' channel is targeted.

Implementing new ideas (the substance of the second part of the WT definition) may be more difficult or slower within large, incumbent firms, so that new economic opportunities are often pursued through start-ups or within small incumbent firms that have a less hierarchical structure and are more flexible (see Crafts, 2012). If so, start-ups, small firms or self-employment rates may not be a poor measure of entrepreneurship. The UK self-employment rate is plotted in Figure 4-1. This shows an upward trend over time, though there are clear breaks in trend; the steepest increase came between 1979 and 1989, and the series flattens off somewhat in later decades. Of course movements in this series reflect certain important changes to the UK tax schedule that distorted the margin between self-employment and incorporation, such as corporation tax reforms. Gordon Brown's first budget in 1997 announced cuts in the small companies rate from 24% to 21%, and the rate proceeded to drop to 20% in 1999 and 19% in 2002. In addition, the introduction from April 2000 of a 10% starting rate for profits between 0 and £10,000, and the cut of the starting rate to 0% in 2002, led to a surge in the number of new companies as the self-employed were tempted to incorporate, paying themselves through dividend distributions rather than salaries (Crawford, 2008). The starting rate was scrapped altogether in 2006.

Obtaining better proxies of entrepreneurship for a long enough time series is difficult, though for more recent years country-level data is available. The Global Entrepreneurship Monitor (GEM) provides survey-based cross-country indicators measuring the rate of 'nascent' ("actively

[3] However, insofar as the incentive mechanism (the chosen policy variable) may stimulate the accumulation of human capital, that growth mechanism is not ruled out. I come back to this point in the conclusions chapter.

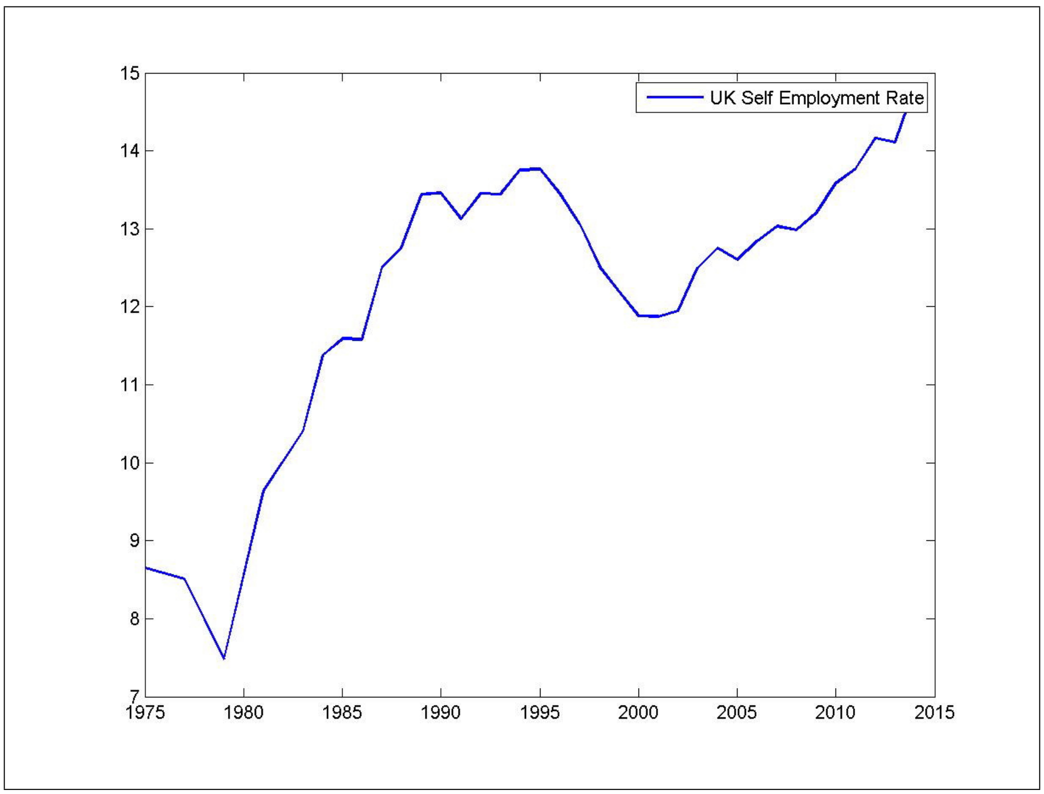

Figure 4-1: UK Self-employment Rate. Source, ONS.

involved" in setting up a business that has been operating for less than 3 months), 'new' (owner-manager of a business in operation for between 3 and 42 months) and 'established' (owner-manager of a business operating for more than 42 months) entrepreneurs in the adult population, based on a sample of at least 2000 adults in each country (Reynolds et al., 2005). Other measures are the OECD-Eurostat Entrepreneurship Indicators (OECD, 2009), the World Bank Entrepreneurship Survey (World Bank 2011), and the OECD high-growth firm indicator. These aggregate measures all characterise a country as more entrepreneurial if there are more individuals attempting to mount new business ventures or if there is a higher rate of formal incorporation (Acs et al., 2014).

There are also measures of entrepreneurial attitudes, both of entrepreneurs themselves and of society towards entrepreneurs, such as the Eurobarometer Survey (Gallup, 2009), the International Social Survey Programme (1998), and GEM; while these measures are certainly interesting, we "do not know whether attitudes drive or are driven by entrepreneurial action" (Acs et al., 2014, p. 20).

Finally, there are measures of framework conditions, measuring the national regulatory environment in which entrepreneurs mount and subsequently run a new venture, such as the World Bank's Ease of Doing Business Survey (Djankov et al., 2002). Such indicators measure the extent to which a country's environment is favourable to entrepreneurs; whether entrepreneurial activity actually follows may depend on additional factors (Acs et al., 2014). In terms of the model in Chapter 2, framework activities belong in the policy variable τ_t' rather than in the variable standing for time spent in entrepreneurial activities z_t. The Global Entrepreneurship and Development Index (GEDI) developed in Acs et al. (2014) interacts individual level measures of attitudes and aspirations with country-level institutional indicators so as to embed entrepreneurial activities in their framework context. The effect is that – in terms of this model – z_t and τ_t' are conflated into one measure.[4] The index has only existed since 2010, and the methodology has since changed such that previous years are not comparable to the current measures – so there is no scope to use it in a single country time series analysis.

[4] This might actually be desirable for our study. A limitation here is that we cannot tie the policy variable's impact on growth tightly to the entrepreneurial channel in Chapter 5, so an interaction at the level of the policy variable with entrepreneurship variables would go some way to addressing this. Unfortunately, there is insufficient time series data for us to explore this.

The model investigated in Chapter 5 assumes productivity growth to be a stochastic process determined systematically by a choice variable z_t, notionally time spent in any or all of the heterogeneous entrepreneurial activities admitted by the WT synthesis definition (eq. 2.42). There is a marginal 'tax' or 'penalty' rate on z_t, reflecting the extent to which z_t is penalized by the policy environment i.e. by regulatory barriers (which raise both sunk costs and operational costs for businesses) and profit taxes (which reduce the appropriability of entrepreneurial returns). Data for the penalty rate is an index composed of factors identified in the literature as affecting entrepreneurial decisions. A systematic relation between productivity growth and the disincentives to entrepreneurship is derived from the model's optimality condition with respect to the entrepreneurship choice (See Ch.2, eq. 2.53). In this way entrepreneurship itself is bypassed and no data on entrepreneurs is required for the model's solution and simulation. The onus is therefore on the choice of data for policy determinants of entrepreneurial activities; as long as these can be confidently related to the activities of entrepreneurs as we have defined them (and not to other growth drivers), and those relationships can be reasonably calibrated, then the model being tested is a model of entrepreneur-driven growth. These links (from entrepreneurship to growth, and from policy to entrepreneurship) are investigated further below in the review of existing literature; I look at the theoretical literature and then the empirical literature.

4.3 Locating the Entrepreneur in Theories of Growth

4.3.1 Schumpeterian Growth Models

Above, emphasis was placed on the importance of competition and free entry in the mechanisms through which entrepreneurs can drive technological progress, partly on the basis of Schumpeterian theory. At this point it might be objected that in appealing to Schumpeter's definition of entrepreneurship we include all profit-motivated innovation and therefore allow 'entrepreneurship' to embrace R&D. Indeed, distinguishing clearly between these two concepts is extremely difficult, and I return to this issue later.[5]

[5] The approach taken in this chapter and the next is to look separately at the broad types of policy generally used to target each of these 'channels' – while the channels themselves are perhaps not wholly distinct (there

Endogenous growth models that are Schumpeterian by design, such as the creative destruction model of Aghion and Howitt (1992), generally dispense altogether with the word 'entrepreneur', focusing instead on the innovator. Innovation in these models is then defined as quality-improving technological change produced by profit-maximising agents in the research and development sector. In other words, the focus is on invention, albeit a profit-motivated kind. Though Aghion and Howitt (1998) define their research activity as broader than formal R&D, when we look at how this model is taken to the data, innovation is generally proxied by formal R&D expenditure and patent counts.[6] R&D expenditure is dominated by large established firms, and the evidence cited in favour of this growth channel therefore tends to exclude innovation by small businesses and by new businesses (which are generally also small). This is discussed in more detail in Chapter 6.

Schumpeter adopted a different position on the role of start-ups versus large established firms in the innovation process in other work (Schumpeter, 1942), arguing that incentives to innovate depend upon the ability to capture monopoly rents in order to recoup the costs of innovation; ex post perfect competition forces price instantly to equal marginal cost and leaves the innovator bearing a loss. Larger firms can exploit economies of scale in innovation by developing specialised R&D departments, and market power offers economic rents to cover up-front innovation costs. The Aghion and Howitt model (1992) is therefore Schumpeterian in assuming that the innovator is incentivised by monopoly profits and that innovation is best produced in a formal research sector ('Mark II'), while also drawing on Schumpeter 'Mark I' in that innovation is driven by creative destruction, as the entry of a successful researcher into intermediate goods production entails the destruction of existing producers.[7]

The model assumes a competitive research sector from which a successful innovator rises to replace the incumbent monopolist in the intermediate goods sector. The intermediate good is

are cases in which entrepreneurship involves R&D and vice versa), and certain policies may incentivise both at once, it seems that subsidies to private sector R&D can reasonably be thought to target the R&D channel rather than the entrepreneurial channel.

[6]"When it comes to measuring the input to the innovation process, empirical researchers routinely limit themselves to expenditures on formal R&D, [...] It is important to keep in mind that when we refer to 'research' or to 'R&D,' what we have in mind is the whole range of inputs to innovation, not just the small part that is actually captured in formal R&D statistics." (Aghion and Howitt, 1998, p. 8)

[7]See e.g. Andersen (2012) for the 'Mark I' and 'Mark II' nomenclature. The difference in emphasis centres on the innovation-maximising level of market competition and the role of the independent 'man of business' in the process.

an input to (perfectly competitive) final goods production, and innovations raise the productivity of the input in that process, arriving according to a Poisson process. Innovations are quality-improving, and a newer quality is a perfect substitute for the older. One firm supplies the whole intermediate goods market, there is a constant markup, and the incumbent's innovation is protected by a perpetual patent ensuring monopoly rents until the next innovation arrives. However, other researchers are allowed to use the patented innovation in creating the next. This creates an intertemporal spillover effect, increasing the rate of technological progress for society; though this externality is not internalised by the innovator whose incentives are undermined. There is also an appropriability effect that arises because the current monopolist is unable to capture the full consumer surplus generated by his innovation today. Spillover and appropriability effects force the equilibrium growth rate to be lower than the social planner's optimum. The model also features Arrow's replacement effect (Arrow, 1962): the incumbent has no incentive to innovate, as the present value of a new successful innovation net of the destroyed value of the current innovation (plus the cost of innovating) is significantly lower than the value of the current monopoly. In other words, the incumbent would rather not destroy its existing rents.[8]

A corollary of this is that entrants' incentives to innovate are higher than the incumbent's, so the model exhibits a "business stealing" effect which counteracts the appropriability and spillover effects. This potentially leads to a higher than optimal level of innovation in the decentralised economy. The model also has the property that current research is decreasing in expected future research, since future research raises the arrival rate of the next (destructive) innovation and hence the destruction of the incumbent monopolist's profits. This admits the possibility of a 'no-growth' equilibrium, where so much future research is expected that current research is deemed not to be worth it.

The welfare policy recommendations depend on the relative sizes of these opposing effects. If appropriability and spillover effects dominate the business-stealing effect leading to a lower than optimal level of innovation, the policy priority is to protect the innovator's monopoly, incentivising research which is socially desirable (e.g. Grossman and Helpman, 1991). The

[8] This might not hold if R&D costs were much lower for the incumbent than potential entrants; in Aghion and Howitt (1992) their R&D costs are assumed to be the same.

purchase of intermediate goods in the final goods sector must then be subsidized to offset the monopoly's negative externality, since the markup leads to a lower than optimal demand. In this setup, barriers to entry (other than by a replacement monopolist) are helpful to innovation and welfare, provided of course that subsidies are financed via lumpsum taxes. The model also recommends subsidies to research (generally identified with R&D), to ensure that monopolies are only temporary, allowing the creative destruction process to work. However, with too much monopoly power in the intermediate goods market (i.e. with too low an elasticity of demand for the intermediate good), offering high super-normal profits, the business-stealing effect dominates and there is 'excessive' research in the economy from a welfare perspective; growth is too high relative to the social planner's optimum which would take account of the incumbent's losses at the hands of creative destruction. Note that, whatever the welfare policy recommendation, the growth policy is clearly to protect monopoly: "*product market competition is unambiguously bad for growth*" in this baseline model (Aghion and Howitt, 1998, p.58, their italics), reducing rents and hence innovation incentives.

The model raises political economy issues in distinguishing between the incentives of incumbents and researchers. A tax on research activity would be distortionary and lower the economy's innovation rate; it would also fall solely on potential entrants (the only ones investing in research due to the replacement effect) and would therefore be lobbied for by the incumbent, since it would slow down the rate at which their profits are destroyed (Acemoglu, 2008).

In terms of consistency with the empirical evidence, the baseline 1992 model falls short in certain key respects. Nickell (1996), for instance, finds a positive association between competition and productivity growth; Crafts (2012) lists more evidence in this vein. This illustrates the limitations of the ex post monopoly setup in the Aghion and Howitt (1992) model, which simply does not allow for this relationship, or for incumbent firms to contribute to innovation to an extent matching the data. Competition and entry can only spur innovation among incumbents in a monopolistic framework when considerable complexity is added. Thus Aghion and Howitt (1998, Chapter 7) and others have proposed various modifications and extensions to the 'Schumpeterian' model, allowing intermediate goods market competition to enhance productivity growth under particular circumstances. Aghion et al. (2013) refer to this line of research as "Growth meets IO" (p.6). One such model features an 'escape entry' effect which allows incumbent firms a role in driving innovation (Aghion and Howitt, 2006). New entry or the threat of new entry "enhance innovation and productivity growth, not just because these are the direct result of quality-improving innovations from new entrants, but also because the threat of being driven out by a potential entrant gives incumbent firms an incentive to innovate in order to escape entry" (*ibid.,* p.282). They use a multi-sector model in which an incumbent monopolist in each sector earns rents that are threatened by new entry, which occurs with some probability. The monopolist's decision on whether to innovate or not depends on his proximity to the technology frontier. If he is near to it then he will innovate and see off the entrant, exploiting a first-mover advantage; if not, he exits. Given a certain level of proximity to the technology frontier, the model implies that entry or the threat of it raises productivity growth, more so when the probability of entry is high. Entry, exit and turnover are important for growth, and their absence is "an important part of the explanation for the relatively disappointing European growth performance over the past decade" (*ibid.*,p. 280).[9] Contrast the product variety model (Romer, 1990), in which exit must lead to lower innovation (*cet. par.*), decreasing product variety.

Aghion and Howitt (2006) also note a closely related 'escape competition' effect, whereby in "neck-and-neck" industries (i.e. provided that incumbent firms in an oligopolistic industry are similar in technological capability,) innovation allows the firm to "break away from the constraints of intense competition" (p. 280), since not innovating would lower rents by more than innovating would. Such step-by-step models generate testable predictions, including: 1) competition enhances growth near the frontier but reduces it far from the frontier, 2) competition has an ambiguous effect on aggregate innovation depending on the proportion of neck-and-neck industries in the economy, and 3) stronger patent protection and competition are complementary policy instruments near the frontier, both enhancing innovation through their effects on the profit motive - competition spurs innovation by undermining profits for near-frontier firms that choose not to innovate, while patent protection enhances expected profits for near-frontier firms that do innovate (Aghion et al. 2013).[10]

[9] Evidence cited for this is Nicoletti and Scarpetta (2003).

[10] For regression evidence supporting these predictions, see Aghion, Akcigit and Howitt (2013, pp. 13-14).

Acemoglu and Cao (2010) describe a Schumpeterian model with quality improvements and creative destruction, in which both incumbents and entrants innovate. In this particular setup, the linearity (rather than concavity) of the incumbent's innovation production technology gives the model an unambiguous prediction that entry barriers (or taxes on entrants) actually raise growth, as does lowering taxes on incumbents. A tax on entrants could be interpreted as a strict patent policy, whereby entrants must pay the incumbent to use his innovation in the R&D process, unlike in the baseline Aghion and Howitt model. A tax on entry also raises welfare, since the decentralised equilibrium entails too much entry due to the business stealing effect. This policy prescription is at variance with the 'step-by-step' models just described, in which both stronger patent protection and greater competition actually promote growth in neck-and-neck industries.

The bottom line seems to be that creative destruction models can be constructed in such a way as to imply various distinct (and often conflicting) policies regarding barriers to entry, competition and intellectual property protection and their effects on the growth rate. Ultimately, which of these models applies (whether at the aggregate level or the industry level) is an empirical matter. Here, the aim is to highlight the prediction of some of these models (and the suggestion of empirical evidence gathered in e.g. Crafts (2012)) that barriers to business entry are harmful to innovation, while competition enhances it, via Schumpeter/Kirzner's innovator. Also noted is the assumed equivalence in all these models between the creative destructor and the researcher or inventor, which has led to the mapping of innovation to formal R&D activity in the data at the empirical testing stage.

4.3.2 Spillover Models

Creative destruction models are not the only models with some claim to the Schumpeterian tag. The knowledge spillover theory of entrepreneurship (KSTE; Acs et al. 2005, 2009) channels Schumpeter 'Mark I' in refocusing the growth driver on entrepreneurs, as opposed to the profit-driven inventors emphasized in the R&D literature motivated by Aghion and Howitt (1992).[11] Braunerhjelm et al. (2010) suggest that the causality from R&D to growth is not as simple as the new endogenous growth theory implies, noting the lack of correlation between GDP growth

[11] Thus the emphasis is more on Schumpeter 'Mark I' and less on 'Mark II'.

and the R&D spending to GDP ratio for 29 OECD countries between 1981 and 2002. It is worth beginning with a brief discussion of Romer's knowledge spillover theory (Romer 1986, 1990), since KSTE draws heavily on it.

The Romer (1986) model follows Arrow (1962) and Shell (1967) in making aggregate knowledge accumulate as a costless by-product of the individual firm's capital accumulation, due to its nonrival and partially excludable nature:

> "investment in knowledge suggests a natural externality. The creation of new knowledge by one firm is assumed to have a positive external effect on the production possibilities of other firms because knowledge cannot be perfectly patented or kept secret." (p.1003)[12]

Knowledge is supposed to be embodied in physical and human capital; Romer (1990) emphasizes spillovers from human capital. Some research technology is assumed that can transform foregone consumption into new knowledge, which spills over to the aggregate knowledge stock; the process is motivated by "learning-by-doing" (Arrow, 1962), since investment in capital gives the firm and its labour force experience which raises effectiveness in production. Knowledge spillovers overcome private diminishing returns to capital in production leading to constant or even increasing returns, but the spillover is not internalised by private firms who do not account for their effect on the aggregate. The competitive equilibrium is therefore Pareto inferior to the social planner's optimum in which all firms would invest more in research, as in Aghion and Howitt (1992). Government intervention is required for firms to accumulate knowledge at the optimal rate; "Any intervention that shifts the allocation of current goods away from current consumption and toward research will be welfare-improving." (Romer, 1986, p.1026) Interventions are subsidies financed by lumpsum taxation, adjusting the (after-tax) private marginal product of knowledge to equal its social marginal product.

Unlike the 1986 model, in which growth is a by-product of investment and firms do not intentionally invest in knowledge generating activities, later spillover models allow analysis of how growth arises endogenously from firms' R&D decisions. Monopolistic competition is introduced in expanding input variety models (Romer 1987, 1990), in which a greater number of

[12] This observation also underlies the Aghion and Howitt (1992) growth mechanism.

inputs generates increasing returns in final goods production through greater specialisation and division of labour. Input varieties are therefore complements in production, and researchers aim to invent new varieties. The producer of each input is a monopolist whose markup is protected by patent, creating a pecuniary externality that drives a wedge between decentralised and Pareto optimal equilibrium. This wedge is compounded by technological spillovers; past R&D spills over to current R&D so that skilled labour is more productive over time and existing ideas are inputs in the knowledge creation process. The decentralised innovation rate is again lower than the social planner's equilibrium, since firms ignore the effect of their own R&D expenditure on aggregate productivity. The policy recommendations are, again as in Aghion and Howitt (1992), markup-correcting subsidies to final good inputs and subsidies to research to correct the disincentive effects of technological spillovers, financed by non-distortionary taxes.

We now turn to the knowledge spillover theory of entrepreneurship (Acs et al., 2009), which starts with the question of where entrepreneurial opportunities themselves come from, rather than taking the existence of opportunities as exogenous and simply noting the role of entrepreneurs in discovering and exploiting them (as has been the tendency in much literature on entrepreneurship). Following Romer (1990), they assume that knowledge – 'economic knowledge' as opposed to general knowledge, cf. Arrow (1962) – is a factor of production. Firm-level investment in this factor yields an intertemporal spillover from present to future economy-wide knowledge. This investment in knowledge production is equated with profit-motivated R&D activity in incumbent firms, and the source of entrepreneurial opportunities is then identified as spillovers from that activity.

Acs et al. (2005, 2009) note that Romer's theory does not offer an explanation of how or why knowledge spills over from firm-specific R&D to the wider economy, though he divides economic knowledge into a non-rival, partially excludable part (published research or patent documentation) and a rival, excludable part (personalised or tacit knowledge, embodied in individuals and networks). Their innovation is to add an intra-temporal spillover from incumbent firms investing in R&D to entrepreneurial start-ups, who convert newly produced knowledge into economic knowledge by perceiving unexploited opportunities for commercialisation. This arises because higher than usual uncertainty and information asymmetry are associated with new knowledge that is yet to become economic knowledge, leading to divergent estimates of expected value (mean and variance) across agents (Arrow, 1962). The intuition is that incumbent firms may undervalue newly generated knowledge, allowing that (personalised) knowledge to be appropriated and commercialised by a start-up (a former employee or network member). As such, incumbent R&D generates entrepreneurial opportunities.

It follows that entrepreneurship is an important conversion mechanism for knowledge to become economic knowledge, the more so when incumbent firms fail to internalise the economic potential of the knowledge they purposefully create, as may occur due to suboptimal incentive structures within the firm. The stated implication is that strong intellectual property protection (IPP) hampers intra-temporal knowledge spillovers and so innovation and growth. IPP allows all rents from knowledge creation to accrue to the knowledge producer, so incentivising investments in knowledge production; but if the knowledge producer undervalues his R&D product he will not take the important step of commercialising it, so keeping growth below potential. The assumption is that incumbent firms have intrinsically lower commercialisation capabilities than entrepreneurs.

In the theoretical model (Acs et al. 2009), a representative consumer derives utility from consumption of differentiated goods, produced by monopolistically competitive firms. Product innovations in the form of new varieties and quality-improvements to existing varieties arrive as a result of R&D investment by incumbents and/or by start-ups combining existing knowledge in innovative ways, via Poisson processes; these two mechanisms are described by separate innovation functions. Both types of innovation incur fixed costs, requiring funds to be raised on financial markets; both pay risk premia on loans, since all firms face the threat of entry which would reduce profits. The model has the scale effect that more researchers increase the probability of innovation (cf. Romer, 1986, 1990; Aghion and Howitt, 1992) and more R&D investment will raise innovation and growth; subsidies to R&D should therefore promote growth, ceteris paribus. A higher exogenous level of average entrepreneurial ability in the economy raises innovation from entrepreneurship (*cet. par.*), and a higher stock of knowledge will increase entrepreneurship, providing more opportunities through the intra-temporal spillover.

The important prediction of their model for our purposes is that entrepreneurship is decreasing in regulatory and administrative burdens and in government intervention in markets. This effect is termed "barriers to entrepreneurship", which include labour market rigidities, taxes and bureaucratic constraints.[13] Barriers to entrepreneurship are captured in their model by an efficiency parameter, σ, reflecting "how smoothly a new discovery is introduced in the market", though interestingly this parameter enters the R&D-driven innovation function as well as the entrepreneur-driven innovation function. This illustrates a difficulty that we will encounter here as well, the fact that the same barriers to entrepreneurship (in the form of start-up) may also be barriers to the commercialisation of knowledge by incumbent, knowledge-producing firms – i.e. many incumbent firms conduct R&D and commercialisation activities that would be hampered by barriers that we might characterise as 'entrepreneurship barriers'. These barriers to commercialisation would then disincentivise R&D itself, rather than operating on a distinct entrepreneurial channel. The implicit assumption in terming them "barriers to entrepreneurship" may be that all commercialisation of new knowledge deserves to be called entrepreneurial, or that entrepreneurs have a higher propensity to commercialise new knowledge than incumbents (a priori, incumbents are bad at this) so that these barriers are more relevant to start-ups (entrepreneurs) than to incumbents.

Braunerjhelm et al. (2010) use a model in which the distribution of scarce resources between R&D and entrepreneurial activities is just as important for growth as purposeful investment in knowledge creation (cf. Michelacci, 2003). In their KSTE model, both incumbent (knowledge producing) firms and entrepreneurs commercialise new knowledge, but with explicitly different levels of efficiency in contrast to Acs et al. (2009). They note that cross country differences in these efficiency parameters may explain how a small knowledge endowment may nevertheless translate into a higher level of growth than a country with a larger endowment of knowledge but whose commercialisation process is inefficient; the efficiency parameters are termed "knowledge filters".

In the model, the individual weighs the expected net payoff from entrepreneurial activities (uncertain) against the expected net payoff from being an employee (a certain wage), and the relationship between these payoffs decides the distribution of labour between these activities. The share of entrepreneurs increases as commercialisation efficiency rises (equivalent to a decrease in the entrepreneurial knowledge filter), as well as with policies that increase the expected pay-

[13] They also note the role of culture, traditions and institutions, which are out of scope for the present paper – culture and traditions are too difficult to measure, and fundamental institutions are stable over the period examined for the UK.

off to entrepreneurship, "e.g. through lowered taxes" (p.110). When the regulatory burden is reduced and when knowledge is made more accessible, profits from entrepreneurial activity are associated with a lower level of uncertainty, which also reduces the entrepreneurship knowledge filter.

Braunerhjelm et al. (2010) note that models in which growth is generated through human capital accumulation or R&D investment suggest policy instruments relevant to those mechanisms, i.e. incentives to invest in human capital and knowledge (e.g. Lucas, 1993): "Thus, the policy debate on how to generate growth revolves around the efficacy of a combination of taxes and subsidies in order to promote education, public and private investments in research and development, training programmes and apprentice systems." (Braunerhjelm et al., 2010, p. 122). The principal relevance of their paper for our purposes is in their recommendation of a different set of policy instruments affecting the "entrepreneurial choice", responsible for transforming new knowledge into economic knowledge. While the suggestion is not that investment in new knowledge is unnecessary for growth, the conclusion is that it is not sufficient. The entrepreneur is the "conduit" for knowledge spillovers, which prevent diminishing returns in production from setting in.

Acs and Sanders (2013) build on a similar KSTE model but enrich the spillover structure. In this model, all opportunities for commercialisation resulting from R&D in incumbent final goods-producing firms spill over intratemporally to entrepreneurs operating in the intermediate sector upstream – that is, no spillovers are absorbed by incumbents. Start-up firms enter the intermediate sector in the pursuit of positive expected rents accruing to "commercialization, not invention" (p.781). To this is added an intratemporal spillover from entrepreneurship in the intermediate sector to incumbent R&D (a downstream spillover). These intratemporal spillovers are bolted onto the Romer (1990) expanding varieties model, so that there are intertemporal spillovers from current to future innovation. Again, the message is that "Policy makers would be seriously misguided in focusing exclusively on knowledge creation" (Acs and Sanders, 2013, p. 787). The decentralised market equilibrium balanced growth rate is an analytical function of the various spillover parameters, as is the social planner optimal growth rate when all externalities are internalised. Policy can adjust the equilibrium growth rate by manipulating the allocation of skilled labour between R&D and entrepreneurship, so as to replicate the social optimum. However, it is not clear a priori how the allocation should be adjusted until the spillover parameters are robustly estimated, since it will depend on the relative sizes of the various parameters. This theory incorporates considerable complexity in the growth process, but is difficult to take to the data; its policy recommendations for the UK remain obscure.

4.3.3 Innovation Under Perfect Competition

The creative destruction and knowledge spillover models share a reliance on monopoly rents in motivating entrepreneurship. Such models often emphasize the necessity of legally granted monopoly rights to safeguard the rate of innovation (with the notable exception of KSTE, which may imply the reverse, though still relying on innovation spillovers for growth to occur). Boldrin and Levine (2002) point out that assumptions of non-rivalry in technology - leading to costless spillovers - and of a fixed cost of innovating have led much modern endogenous growth theory to discard perfect competition as a viable market framework, since innovation must incur a loss. However, they argue against the existence of costless spillovers, since ideas are embodied in a person or good and their transmission is costly. An idea may exist in the abstract but it is economically valueless until someone has understood it, which takes time; likewise an idea may be embodied in a good which must at least be paid for before that idea can be replicated by someone else. Therefore the appropriability problem attached to spillovers of technology is not necessarily an issue; the non-rivalry assumption is somewhat relaxed. They note "a great deal of less formal evidence that shows that innovation can thrive under competition; and that government grants of monopoly power are more prone to lead to socially costly rent-seeking behaviour than to foster innovation and growth." (p.4). Like Scotchmer (1991), they emphasize that legal grants of monopoly power giving the inventor control over how his innovation is used by others have the effect not only of enhancing the inventor's original incentive, but also of reducing future incentives to innovate off the back of that innovation.[14]

They argue instead for a model in which innovating entrepreneurs are granted no legal monopoly but benefit from "a well defined 'right of sale'" (p.2); that is, the value of privately produced commodities is fully appropriable. Entrepreneurs seek profit opportunities:

[14] This observation is at the heart of Aghion and Howitt's 'escape competition' effect. See e.g. Aghion and Howitt (2006).

> "Technological progress takes place because entrepreneurs find it advantageous to discover and produce new commodities. These new commodities themselves may make profitable the employment of new activities that make use of them. Although, in the ensuing equilibrium, entrepreneurs do not actually end up with a profit, it is their pursuit of profit that drives innovation." (p.3)

Thus the interaction of entrepreneurs in competitive markets is itself the source of profitable opportunities, though supernormal 'profit' itself is absent from the construct in general equilibrium. This is precisely the situation in the model examined in this chapter.

The standard assumption is that the ability to copy an innovation freely in a perfectly competitive market undermines the incentive to innovate at all, but Boldrin and Levine argue that there are ways of recouping innovation costs that have little to do with long run or even medium run monopoly rents. In the highly competitive cases of fashion, open software, basic scientific knowledge, advertising (the list continues), a lack of effective intellectual property protection does not undermine the rate of innovation. They explain that returns to technological progress generated by the entrepreneur accrue formally in the model to fixed factors of production:

> "If you are good at writing operating systems code when the personal computer technology is introduced, you may end up earning huge rents, indeed. In principle, this model allows a separation between the entrepreneurs who drive technological change by introducing new activities and the owners of fixed factors who profit from their introduction. However, it is likely in practice that they are the same people... In the end, it is necessary only that the rent accruing to the fixed factors comprising the new idea or creation cover the initial production cost." (p.18)

In the next chapter, we test the model (presented in general terms in Chapter 2) assuming z_t to be characterised as entrepreneurial activities by the choice of policy variable. As in KSTE, it is assumed that a reduction in policy-related barriers to entrepreneurship has a positive effect on productivity growth over the short to medium run. The stylized setup is as follows: future 'profits' from the entrepreneur's decision to dedicate time to enhancing the technology used by the incumbent firm (which the entrepreneur owns through shares) will, in general equilibrium, enter the household budget through higher wages, though in the optimisation problem the entrepreneur takes the wage as given and envisages profits accruing to him via a higher dividend stream. In this respect there are important similarities to the approach of Boldrin and Levine (2002). I assume that competitive rents to factors of production are sufficient to cover production costs, including the sunk cost of innovation which in this model is the current labour wage foregone and the policy-related penalty incurred as a result of spending time in entrepreneurial activities.

The model does not emphasize the non-rival, partially non-excludable nature of innovation, and in this we depart from the spillover literature. Therefore the policy recommendation of the model used here is not for the government to intervene by granting legal monopoly rights, for example, in order to correct a socially sub-optimal level of innovation in decentralised equilibrium. The penalty variable represents any wedge between the returns that would come back to the shareholding household as a result of higher firm-level productivity in a frictionless market, and the returns after-tax; that is, it represents any distortion to the personal appropriability of productivity increases resulting from entrepreneurship.

Since the tax/policy penalty is on the growth-driving margin by construction, the revenues it raises will be undermined by the revenue foregone in terms of lost growth. Moreover, a proportion of this 'tax' is in fact badly designed regulation. If regulation is poorly designed or delivered (i.e. the costs of complying are excessive) - if it does not correct a market imperfection but in fact creates one – then it represents not a straightforward welfare transfer from the firm to the consumer (as in the case of well-designed regulation) but a deadweight loss to society. Legal grants of monopoly power would constitute a barrier to entry in this model which would, in theory, belong in the entrepreneurial 'tax' rate.

The model used in this work abstracts from the complexities introduced by formal indivisibilities, business stealing effects, spillovers, and interactions between entrants and incumbents; in short many aspects of the models discussed above which may recommend them for certain purposes or in the case of certain industries at a more microeconomic level. What we are interested in is the policy predictions that these models have, some of which are shared by the present model. In its relative simplicity, this model offers a convenient vehicle for testing some of these predictions against the UK experience.

Entrepreneurship has traditionally been excluded from the neoclassical framework on the basis that the uncertainty, improvisation and creativity inherent in entrepreneurship are impossible within it (Kirzner, 1985; Wennekers and Thurik, 1999). The present model introduces entrepreneurship to the problem of a rational optimising agent operating in a perfect competition general equilibrium model with full information.[15] In doing so, I appeal to Milton Friedman's 'as if' methodology (M. Friedman, 1953). Assumptions of full information, of rationality and perfect competition provide a simplifying framework in which to test the hypothesis of interest; namely whether a causal relationship from tax and regulatory policies around entrepreneurship to economic growth is to be found in the UK macroeconomic data. In reality the aggregate relationship between these variables is the result of myriad mechanisms operating at the microeconomic level, in a variety of contexts. However, a theory is not to be judged by its "descriptive accuracy" but on its "analytical relevance" (Friedman, 1953, p.166) and, in general, simpler theories (provided they can explain the phenomena of interest) are preferable to complex theories:

"A hypothesis is important if it 'explains' much by little, that is, if it abstracts the common and crucial elements from the mass of complex and detailed circumstances surrounding the phenomena to be explained and permits valid predictions on the basis of them alone. . . . the relevant question to ask about the 'assumptions' of a theory is not whether they are descriptively 'realistic', for they never are, but whether they are sufficiently good approximations for the purpose in hand. And this question can be answered only by seeing whether the theory works, which means whether it yields sufficiently accurate predictions." (1953, p.153)

By "accurate predictions" is meant not the ability to forecast future events correctly but the ability to observe the model's implications for macroeconomic phenomena in historical data (p. 157). For Friedman, a model's strength has nothing to do with the reality of its assumptions; in fact those may be diametrically opposed, since realistic assumptions will necessarily be complex and thus weaken the theory, making it less general. Therefore a model should not be judged on the ability of its assumptions to fit the data, but on its ability to generate behaviour that

[15] Acs et al. (2013) take a similar position. "It may strike entrepreneurship scholars as odd to develop a general equilibrium model of Schumpeterian entrepreneurship. Schumpeterian entrepreneurs are, after all, upsetting the static Walrasian equilibrium by introduction (radical) innovations. It should be noted, however, that this model is not intended to describe the entrepreneurial process at the micro level but rather models its implications at the macro level. We have to abstract from a lot of micro level heterogeneity and Knightian uncertainty to focus on the macro-level impact of an entrepreneurial process that on average generates a flow of innovations that create growth in a dynamic, steady-state equilibrium." PAGE REF.

mimics real world data in certain dimensions of interest. This is 'paramorphic' modelling; contrast the 'homeomorphic' modelling endorsed by many behavioural economists (Wakker, 2010, p.3), in which not just the outcomes generated by a model but also its assumptions must fit the data to some level of 'realism'. The approach here aims for simplicity, on the basis that adding complexity obscures the interpretation of the indirect inference test results reported later in this chapter. It may be that some of the assumptions made here are wrong in a fundamentally important way, affecting the model's data generation process and therefore its fit to the observable data. If so, the model should be rejected at the testing stage and its assumptions subsequently adjusted (or thrown out). However, if the model is not rejected, the "perceived discrepancies between the 'assumptions' and the 'real world"' are unimportant for the particular economic relationship the model is designed to explain.[16]

The last important point to lift from Friedman's 1953 essay is that "In general, there is more than one way to formulate such a description [of the forces that a hypothesis asserts to be important] – more than one set of 'assumptions' in terms of which the theory can be presented." (p.171) It has been noted that 'Schumpeterian' growth models generally assume a monopolistic industrial structure in which incentives to innovate depend on the appropriability of economic rents. Here, the incentive to innovate likewise depends on the appropriability of take-home profits under perfect competition; tax and regulatory treatment of innovative firms will undermine productivity growth, regardless of the industrial structure. The perfectly competitive model used here mimics to some extent the predictions of Aghion and Howitt's story in terms of the effects of competition and of firm entry and exit on productivity growth (Aghion and Howitt, 2006, 2013). Ultimately it may be that the hypothesis we embed in perfect competition could fit the data equally well (or better) in a model predicated on the assumption of imperfect competition. All that the current study can do is establish whether the particular model used here, with its high level of abstraction, is ruled out as being the appropriate model in selected dimensions of interest, or whether it is still in contention.

Here there is no explicit creative destruction mechanism in the growth process. The model

[16] Note that here the chief purpose is to understand how certain broad types of policy have worked through the entrepreneurial channel to affect economic growth. The contention is that the model I use here, though perhaps incapable of capturing complex policy-entrepreneur interactions at the level of its microfoundations, nevertheless allows us to examine the macroeconomic relationship between policies that we have identified as 'entrepreneur'-relevant and productivity growth.

itself is agnostic on how precisely entrepreneurship causes growth, and a positive linear relationship between time spent in entrepreneurial activity and productivity growth in the consumption good sector is simply assumed, embedded in a perfect competition setup (Eq. 2.53, Ch.2). No firms literally exit in this stylized model. Equally, the entrepreneur does not set up a new firm (unlike Acs et al., 2009, 2013), but simply uses his time to generate new 'productivity' which is fully excludable and can be donated to the existing representative firm that the agent owns. The exogenously existing firm is thus the vehicle for z_t to enhance the entrepreneur's income. But though z_t in this highly stylized model does not involve setting up a new firm, it can be thought of loosely as including such an activity.

Notionally, all 'barriers' to effective operation encountered by the firm over its lifecycle are expected to hamper the TFP growth mechanism here because of an underlying appeal to Schumpeterian theory, however that theory may be formalised elsewhere. Obstacles to setting up a firm deter z_t; future costs anticipated while running a firm, in terms of profit taxes, labour market rigidities, or bureaucratic compliance costs, likewise deter z_t; and an anticipated inability to wind up a commercial venture when it ceases to be profitable will likewise raise the riskiness of entrepreneurship (reducing its expected return) and deter z_t. All these deterrents to z_t, insofar as they are captured in τ'_t, reduce growth in this model, which is consistent with the predictions of Schumpeterian creative destruction theory, as well as the 'knowledge filter' hampering the entrepreneurial spillover conduit in KSTE. Again, if the fundamental assumptions of zero spillovers and perfect competition are importantly wrong, they will lead this simpler model to be rejected by the test, implying that the complexities added by these other approaches at the level of microfoundations are unavoidable. If this model can explain the historical data, on the other hand, it may provide a viable alternative to those more complex formulations.

4.4 Review of Empirical Literature: Policy, Entrepreneurship and Growth

4.4.1 Growth Regressions

This section is introduced with a brief discussion of the 'Barro growth regressions' widely used to investigate policy impacts since Barro (1991). These take the form:

$$g_{i,t} = \alpha \ln y_{i,0} + X'_{i,t}\beta + \gamma s_{i,t} + e_{i,t}$$

where the dependent variable is GDP growth or productivity growth, and regressors are initial income (to control for convergence), a matrix of co-variates to control for omitted variable bias and a policy variable, s. Models of this specification are often estimated in a panel with observations averaged over 5 year periods to smooth out the impact of the business cycle, which might otherwise affect both dependent and independent variables, though such averaging could smooth out informative variation. Barro (1991) uses data on 98 countries between 1960 and 1985.

A cross-section is used in order to obtain counterfactual variation (what would have happened to growth had the policy experience been different?), and a larger set of countries may offer a wider variety of policy profiles, particularly for reasonably long time series. However, there is a problem in assuming parameter homogeneity in a large set of countries with very different characteristics, many of which will be in the error term; this implies that the sample may not be random, if more of one 'type' of country is included than others (Levine and Zervos, 1993).[17] If countries have fundamental differences which affect the response of their growth rates to policy then they will not provide an appropriate counterfactual for each other unless these differences are controlled for in the regression. Controlling for differences using a fixed country-specific effect will not resolve this if the omitted factors vary over time. More regressors can be included to control for observable omitted variables that might be correlated with policy, causing bias, but the loss of degrees of freedom may be prohibitive if the time series is short (furthermore, the omitted driving factors may not be easily measurable).

[17] This sample selection issue boils down to ordinary omitted variable bias (Heckman, 1979).

Even for more similar countries, many variables have been found to be correlated to growth (in different specifications) and the temptation is to include them all. However, regressors can be highly correlated with each other. The more collinearity between regressors, the more difficult to distinguish their individual effects (Loayza and Soto, 2002; Brock and Durlauf, 2001). A more parsimonious regression is preferable, but how to choose between the regressors?

Often a regressor that has been significant in one specification loses its significance when included alongside additional or different regressors (Levine and Renelt, 1992). This problem is often addressed using extreme bounds analysis (Leamer, 1983). When such analysis is conducted, most correlations with growth are discovered to be fragile; i.e. the significance and magnitude of the coefficient of interest is not robust to the addition of other regressors; though some argue that extreme bounds analysis is not an appropriate test, e.g. Sala-i-Martin (1994).[18] Another potential issue is that policy proxies may be inconsistently measured across countries, undermining parameter homogeneity further; this problem can also be expected to diminish when regressions focus on groups of OECD countries. Coefficient estimates are also sensitive to sample outliers.

A separate source of endogeneity in the policy variable (besides omitted variables) is reverse causality. Regressions of growth on policy will be vulnerable to this if policy responds to growth rather than (or perhaps as well as) causing it. This ambiguity over the direction of causation fundamentally undermines the inferred policy conclusions from the estimated coefficients; they represent statistical correlations at most and, as established above, perhaps not even then due to fragility. These problems are not limited to regressions in which GDP or productivity growth is the dependent variable, but may also apply for regressions of other 'outcomes' on policy, such as entrepreneurship or innovation proxies such as R&D expenditure (the R&D literature is dealt with in Chapter 6). For instance, if the regulatory environment changes in response to lobbying by entrepreneurs (rather than driving entrepreneurship), high regulation environments will simply persist when there are few motivated entrepreneurs around, leading to a negative correlation between entry and regulation. A simple regression of entry rates on regulation measures could not then be interpreted as a causal model from policy to entry; moreover, the

[18] See also Sala-i-Martin et al. (2004) for a Bayesian Model Averaging approach to selecting appropriate right-hand side variables in growth regression.

feedback from the dependent to the 'independent' variable will bias the estimation.

When regressors are endogenous, an instrumental variable strategy is essential. Many more recent growth regressions take this approach, arguing - with varying levels of success - for instruments that are exogenous and strongly correlated with the policy variable. More recent studies address regressor endogeneity using a dynamic GMM or GMM system approach (Arellano and Bond, 1991; Blundell and Bond, 1998) in which instruments are the lagged levels or differences of the endogenous regressors themselves. This is viable if their autocorrelation structure satisfies certain requirements.

While it may not be entirely fair to conclude that "Ultimately this line of research is a dead end if the aim is to understand what causes growth so that we can improve the situation" (Myles, 2009b, p.16), the literature review which follows is conducted bearing the preceding discussion firmly in mind.

4.4.2 Entrepreneurship and Growth

Carree et al. (2002) look at the relationship between per capita GDP and business ownership in a panel of 23 OECD countries for the period 1976 to 1996. Business ownership is the number of business owners for all sectors (except agriculture) as a proportion of the labour force, and therefore measures the stock of self-employed businesses rather than new business creation. However, these may be correlated and they argue that the business ownership rate is a reasonable, though imperfect, proxy for entrepreneurship.[19]

Estimating a two-equation error correction model with weighted least squares they find that deviations of self-employment around its optimal level, $e^*_{i,t}$, incur penalties in the growth rate of GDP per capita, whether deviations are positive or negative. Entrepreneurship is found to follow an error correction process, and the convergence rate back to equilibrium is slow, relying (theoretically) on structural supply side as well as cultural and institutional changes. $e^*_{i,t}$ itself is modelled as a quadratic function of per capita GDP. This is motivated by the observation that self-employment is higher for both poorer and richer countries, while the firm distribution in middle income countries is more heavily dominated by larger firms; thus there is two-way

[19] Across countries the definition of business owners differs in breadth (regarding businesses that are not legally incorporated, for instance), so they adjust the OECD statistics to correct for this. However, they note that issues remain for comparing these rates across countries.

causality in the model between entrepreneurship and income. For the determination of $e^*_{i,t}$, they cannot distinguish statistically between an L-shaped and a U-shaped relationship with the stage of development (cf. Wennekers et al., 2010).

The authors put great emphasis on potential policy implications of the results, drawing the following quote from Kirzner that "government regulation of market activity is likely to obstruct and frustrate the spontaneous, corrective forces of entrepreneurial adjustments" (Kirzner, 1997, p.81). The suggestion is that free entry and "exit free of stigma and financial burdens" are essential for entrepreneurship rates to be allowed to find their equilibrium in the face of shocks, and hence for economic growth to be at potential.

Audretsch and Thurik (2001) look at the same set of 23 OECD countries within the same setup for 1974-1998. They also find that any deviation from the equilibrium rate of entrepreneurship reduces growth; this holds when entrepreneurship is measured both by the self-employment rate and by the share of small firms in economic activity.

Wong and Autio (2005) use Global Entrepreneurship Monitor (GEM) data to look at the macroeconomic impact of entrepreneurship, defined as new firm creation, in a cross-section of 37 countries in 2002. Their aim is to distinguish between the productivity impacts of innovation and entrepreneurship. Innovators can be large and/or established firms conducting formal R&D and as such are not entrepreneurs. Their regression model is a CRS Cobb-Douglas production function, with new firm creation and technological innovation intensity included as separate inputs to production in addition to capital per worker.[20] The dependent variable is GDP per worker, technological innovation intensity is proxied by the ratio of patents to GDP between 1997 and 2001, and entrepreneurship by various Total Entrepreneurship Activity (TEA) measures in turn: high-growth potential TEA, necessity TEA, opportunity TEA and overall TEA. All these measure the number of adults engaged in the start-up process or actively owner-managing a business under 42 months old, as a proportion of the working-age population. Opportunity TEA is entrepreneurship that responds to the existence of potential economic rents, while Necessity TEA entrepreneurship driven by necessity due to lack of alternative employment possibilities (a "refugee" effect; Thurik et al., 2008). High growth potential TEA is a measure not of observed growth by young firms but of the "ambitions and growth expectations" of

[20] They also control for convergence using the starting level of GDP

entrepreneurs.[21]

A priori, faster technological innovation rates, higher overall TEA, higher opportunity TEA and higher growth potential TEA are all expected to raise aggregate growth rates, while necessity TEA is predicted to retard growth on the basis that 'refugees' have lower human capital (Lucas, 1978). However, in their parsimonious regressions the only specification for which entrepreneurship is at all significant is for the high growth potential TEA, significant at the 10% level. Innovation is significant in all specifications. When entrepreneurship and innovation measures are interacted, no significant effect is found; finding no statistical evidence of collinearity between the measures, they conclude that innovation and new firm creation do not extensively overlap in the data: "This confirms what is often described anecdotally and concluded intuitively: that only a very small proportion of entrepreneurs engage in true technological innovation." (p. 345) This assertion relies on a narrow definition of "true technological innovation" as patented innovation, which is questionable. There is evidence that small firms have a lower propensity to patent than larger firms, and that service sector innovation is less likely to be patented (Fontana et al. 2013, Hall et al. 2013). The assumption of exogeneity for the entrepreneurship and innovation variables is dubious, and this is not addressed; they state in the conclusion that a Granger causality approach would be preferable though impossible due to data constraints at the time. Furthermore, given the small sample there is little scope for robustness tests with respect to control variables or model specification. Wong and Autio acknowledge the absence in their findings of a significant relationship between the impact of entrepreneurship on growth and national income, whereas Wennekers et al. (2005) find that the contribution of overall TEA to growth does depend on the level of development. Since the same dataset is used in both studies, the different results show that the conclusions are sensitive to different model specifications. The conclusion that high growth potential firms ('gazelles') have a greater macroeconomic impact than the majority of start-ups contrasts with other work done on employment rates (see Davidsson and Delmar, 2003).

Erken et al. (2008) use the error correction model approach of Carree et al. (2002) to derive the deviation of self-employment rates around their optimum, and use this deviation

[21] To be counted, start-ups must expect high growth potential in 1) employment, 2) market impact, 3) globalised customer base, 4) use of new technology. Such firms make up less than 5% of new start-ups (p.341).

variable to represent entrepreneurship in various regressions of TFP growth on potential determinants. When entrepreneurship is included as an additional regressor in five influential model specifications from the literature (Coe and Helpman, 1995; Engelbrecht, 1997; Guellec and van Pottelsberghe, 2004; Griffith et al., 2004; Belorgey et al, 2006), it is found to be significant and positively related to TFP growth. The conclusions of the original papers are not affected by the inclusion of the entrepreneurship variable, with other regressors remaining positive and significant factors. They also estimate an "all-in-the-family" model, combining all the driver variables of interest from the earlier models (human capital and various R&D measures, as well as catch-up and labour participation rates) with additional controls. The implication is that entrepreneurship is an additional factor in the productivity process and belongs in the endogenous growth literature alongside human capital accumulation and R&D-driver theories.

Acs et al. (2012) estimate a Barro-style regression of GDP growth rates on entrepreneurship (self-employment rates) for 18 OECD countries, using a first-step regression of entrepreneurship on age (the proportion of the population between 30 and 44), unemployment rates and a range of controls to purge the regressor of endogeneity. Among the controls in the 2nd stage regression are R&D intensity, average years of schooling and government expenditure. They find entrepreneurship to be positive and significant in all specifications. The estimates for the impact of entrepreneurship is robust in different samples: 1981-1998 and 1990-1998. Comparing feasible generalised least squares estimates to the 2-Stage LS estimates, the impact of entrepreneurship on growth is five times as large for the instrumental variable approach, though the other coefficients are relatively consistent in magnitude.

Hessels and van Stel (2011) investigate whether export-oriented start-ups drive national economic growth in a panel of 34 countries for 2002-2008, using GEM total early-stage entrepreneurship activity (TEA) measures. A business included in the TEA measure qualifies as export-oriented if more than 25% of its customers are resident abroad. Following van Stel et al. (2005) they use a dynamic model, regressing average growth rates of GDP on lagged levels of TEA and export-oriented TEA, including the lagged growth of GDP per capita as a regressor to capture potential reverse causality, and the lagged GDP level to capture convergence effects. The general macroeconomic environment is controlled for using the lagged level of the Global Competitiveness Index. Noting the potential endogeneity of export-oriented TEA, they instrument it using various other factors including FDI volume, industry structure, inflation and GDP. Export orientation has a positive and significant additional impact on growth in all specifications, above the impact found for entrepreneurship in general, but the result only holds for high income countries. The coefficient on export-oriented entrepreneurship is higher and more significant in the instrumental variable specification. TEA is a significant cause of growth across all specifications and for all levels of income, with the magnitude slightly larger for less developed countries in the sample. The authors acknowledge the small sample size as a limitation of the study.

For other empirical work linking entrepreneurship to growth, see the surveys in Carree and Thurik (2010), van Praag and Versloot (2007) and Karlsson et al. (2004). For evidence at the regional level, see Audretsch and Fritsch (2002).

4.4.3 Regulation and Growth

Theories of Regulation

Theoretically speaking, why do governments regulate markets? According to the public interest theory of regulation (Pigou, 1938), markets are subject to failures arising from information asymmetries, monopoly power or externalities. Governments intervene using regulation to correct market failures and optimise social welfare. For instance, entry regulation filters out undesirable producers, protecting consumers by assuring product quality and allowing resources to flow to their most productive uses. Consequently, higher levels of entry regulation should be correlated with better outcomes than if regulation was absent. Market failures theoretically reduce both allocative and productive efficiency and so their removal by government intervention should allow growth to reach potential.[22]

According to public choice theory, on the other hand, regulation is inefficient and is an instrument of a less than socially benign government, used to extract rents. This may be a result of regulatory capture of the government by interest groups such as industry[23] (Stigler,

[22] On the other hand, Djankov et al. (2002) expect a negative relationship between regulation and growth on the basis that growing countries have fewer market failures (hence their economic success) and consequently less need of regulation. This illustrates the ambiguous causality inherent in the regulation-growth relationship.

[23] If incumbent firms are in control of regulation, they will raise barriers to entry to keep their position secure;

1971) or else the politicians and bureaucrats running the government are rent-seekers, using the compliance process to collect bribes – the 'tollbooth' theory (Djankov et al., 2002).[24]

Djankov et al. (2002) look at the country-level effects of administrative entry costs on aggregate outcomes for a sample of 85 countries, of all levels of development; their paper formed the basis for the World Bank's Ease of Doing Business dataset. Indicators include the number of procedures required, the minimum official time and the official cost as a percentage of GDP per capita associated with starting a business in 1999.[25] They note large variation across countries in these indicators. Running OLS regressions of various outcome variables on the regulation indicators, they find that higher entry requirements are not strongly associated with better product quality, lower levels of pollution or better health outcomes. However, they are strongly positively associated with government corruption and the size of the unofficial economy, and negatively correlated with a survey-based measure of product market competition. They conclude in favour of the tollbooth theory that regulation exists primarily for government officials to distort rents from firms. They acknowledge, however, that these regressions do not control for unobserved cross-country heterogeneity that may be correlated with regulation and that this casts doubt on their conclusions.

Rather than emphasising capture or attributing malign motives to regulators, an alternative theory of regulation is 'government failure'. Under this explanation, regulation is motivated by the public interest but has negative impacts on market outcomes that are unintentional, due to flawed design (perhaps based on asymmetric information) or unanticipated compliance or enforcement burdens which counteract intended benefits. Equally, regulation may impede growth if it is designed primarily with other non-economic objectives in mind, such a human rights protection, wealth redistribution or defence.[26] Hence a government failure from the

therefore we would expect higher regulation to be associated with higher firm level profits and higher market concentration. This view is formulated by e.g. Adam Smith (1776): "To widen the market and to narrow the competition is always the interest of the dealers... The proposal of any new law or regulation of commerce which comes from this order ... comes from an order of men, whose interest is never exactly the same with that of the public, who generally have an interest to deceive and even oppress the public, and who accordingly have, upon many occasions, both deceived and oppressed it." (Book 1, Chapter XI, p. 278).

[24] Public choice theory is sometimes referred to as private interest theory, since it deals with privately motivated regulating bodies (e.g. Klapper et al. 2006).

[25] These are constructed from official legal documents and expert consultation and "almost surely underestimate the cost and complexity of entry" (p.7).

[26] In addition to the motivation of "screen[ing] out potential frauds and cheats", Klapper et al. (2006) note some other potential government motivations underlying detailed bureaucratic requirements attached to start-up:

perspective of growth might not be a failure when assessed on different criteria, and depending on how relevant costs and benefits are quantified and combined in a social welfare function. Though we do not lose sight of this point, the chapter focuses on the growth objective, and it is in these terms that government failure is defined here.

The costs to businesses generated by regulatory compliance constitute a static cost (the direct cost of meeting the requirements of the regulation), impacting the level of output, and additionally may be dynamic and compounding, much like a tax distortion on the intertemporal margin – i.e. they affect the marginal incentive to invest time and money in capital or productive activities. One unit of such investment foregone represents an increasing opportunity cost over time. Since too much regulation may distort decision margins and suppress economic activities which drive growth, while too little may leave market failures uncorrected, also leading to reduced inefficiency, there may be a growth 'sweet spot' for regulation akin to the interior optimum on a Laffer curve. This would imply a non-linear relationship. Conversely the relationship may be monotonic, so that more regulation is simply worse for growth, regardless of the level. The following discussion reviews empirical evidence for the growth impacts of regulation in product markets and labour markets, since this makes up the body of the literature.[27]

Product Market Regulation and Growth

The new endogenous growth theory generates an ambiguous prediction for the impact of product market entry regulation on innovation and growth (see Section 4.3 above).On the one hand, free entry in a creative destruction model undermines the monopoly rents that attract the innovator and compensate for his effort (and for the probability that his time as monopolist will be short-lived); on the other, product market entry regulations discourage potential entrants who drive innovation in the hope of becoming the next monopolist.

By raising barriers to entry, product market regulation (PMR) lowers the number of firms and hence the degree of competition in an industry. Competition can act as a disciplining influence on incumbent firms which, in the absence of entry threats, can operate inefficiently

the information gathered during the process could be useful for tax collection or censuses, and "hence [improve] the public decision making process" (Klapper et al., 2006, p. 592-3). The point is that governments have multiple objectives, some of which may conflict with maximising economic growth.

[27] For a brief overview of other types of regulation in this context, see Frontier (2012).

and maintain rents without innovating further. Additionally, principal-agent problems within the firm tend to increase with PMR, lowering productivity growth, but decrease when the degree of competition is higher (Bloom and Van Reenen, 2007). Competition appears to make profits more sensitive to manager behaviour (Nickell, 1996).

The empirical consensus for OECD countries is that deregulation of product markets since the 1980s has stimulated investment and productivity growth in those countries, for both manufacturing and service industries (Nicoletti and Scarpetta, 2003). Bourlès et al. (2013) look at the influence of competition in intermediate goods sectors on productivity in downstream sectors, controlling for industry distance from the global technology frontier, in a sample of 15 OECD countries and 20 non-manufacturing sectors for 1984-2007. Competition is proxied by entry regulations. They find that higher entry regulation in upstream sectors reduces downstream MFP growth in a non-linear fashion, more so for countries and sectors that are close to the global frontier. Furthermore, the negative effects of regulation appear to affect more units in the sample over time. Their suggestion is that, as downstream markets have become increasingly competitive with increasing global integration, the undermining effects of upstream markups on incentives to invest in MFP improvements downstream have become more intense. This is in line with the neo-Schumpeterian endogenous growth theory which they appeal to throughout.

Indeed, in many cases the channel for this PMR-related growth is thought to have been innovation as measured by R&D or patents (e.g. Griffith et al. 2010). Given that, as Schumpeter observed in his later work, R&D activity is subject to significant economies of scale and is therefore dominated by large firms, these studies are not relevant to the start-up channel emphasised in this chapter, though we must bear them in mind for the interpretation of results in Chapter 5. The interest is on tying the growth impact of PMR to an entrepreneurial channel.

Scarpetta et al. (2002) find, using micro-level data for nine OECD countries between the late 1980s and mid-1990s, that new entrants make more of a contribution to MFP growth than incumbents, and that stricter PMR and labour market regulation both reduce the rate of new firm entry. OECD regulation indicators are used. The negative effect of regulation on MFP is more intense in industries and countries further from the technology frontier, implying that it hinders technology adoption as well as overall innovation. They find that the average firm entrant in the US (the least regulated in the sample) is small relative to other countries, but that firms that survive expand rapidly; in contrast, the average start-up in Europe is larger, and subsequent rates of expansion are slower. The suggestion is that lower entry costs allow market experimentation that is impossible in more regulated countries.

Klapper et al. (2006) investigate whether and how entry regulation drives entry at the firm level, using data on a large cross-section of European firms for 1998-1999. Entry is measured as the ratio of new firms to the total number of firms in that industry.[28] Measures of entry regulation are taken from Djankov et al. (2002). To deal with potential reverse causality, they use a cross-industry, cross-country interaction model with industry- and country-specific fixed effects; i.e. the explanatory variable of interest is the interaction between country-level regulation characteristics and the industry's 'natural' entry rate, proxied by the US rate. Entry costs in the US, as measured by Djankov et al. (2002), are 0.5% of GDP per capita as opposed to the European sample average of 20%, so the US is assumed to provide the counterfactual of what entry would look like in the absence of regulation. The hypothesis is that industries in which the entry rate ought to be high will be most affected by barriers. As they note, it is a difference-in-differences approach and therefore cannot provide an estimate of the absolute impact of entry regulation on entry.

Consistent with their hypothesis, the interaction coefficient is negative and significant at the 1% level, indicating that industries with naturally high entry rates have relatively lower entry rates when country-level entry regulation is high. As an illustration, the estimate implies that entry regulations account for about 10% of the mean difference in entry rates across sample countries between the retail industry (a high entry rate industry relative to the US) and the pulp, paper and paper products manufacturing industry (a low entry industry, relative to the US). This result is robust in various different samples, to removal of outliers and to alternative measures of entry and of regulation, as well as to the addition of further controls (e.g. GDP per capita). They also use a country's legal origin to instrument regulation, arguing that it represents the part of regulation which is predetermined and is exogenous to entry. The significance and sign of the estimate are robust in the IV model, though the instrument may

[28] New firms are firms aged 1 or 2 and surviving at least one year.

still be endogenous. To address this possibility[29] they restrict the sample to relatively small industries which, it is argued, should have little lobbying power to influence the regulatory environment themselves. 'Small' is defined as having an industry share in value added in the countries lowest tertile. The result is again unaffected.

Klapper et al. also consider whether bureaucratic entry barriers screen out unscrupulous potential entrants; if so, and if trustworthiness is a country characteristic, we would expect the impact of regulation on entry rates to be higher when trust is lower. To investigate this, they divide the sample into low-income and high-income countries relative to the sample median, arguing that higher-income countries are less prone to such 'misbehavior' since infrastructure is superior and monitoring more effective; hence if entry regulations are effective at screening markets for charlatans, they should be more effective in low income countries. They find no difference in the estimated coefficient in the two samples.

Other results suggest that entry regulations raise the threshold size of new firms, and that incumbent firms in naturally high entry industries grow more slowly when regulation is higher. This seems to support the hypothesis that entry provides an effective growth stimulus to incumbent firms, both because competition provides a disciplining influence that drives greater efficiency, and because protectionist barriers to entry allow incumbents to restrict quantities. Klapper et al. also find that types of regulation which strengthen intellectual property rights and broaden access to finance have a positive effect on entry, illustrating that not all regulations qualify as barriers to entry. This cautions against a blanket assertion that 'aggregate regulation' is bad for business; qualitatively different types of regulation operate differently on incentives and market outcomes.

Policy Trends in Product Market Regulation

So there is empirical evidence for a link between product market entry regulations and entrepreneurship, or start-up rates; for more on this, see Cincera and Galgau (2005). This literature, as well as the advent of cross-country rankings through the World Bank Doing Business Indi-

[29] The possibility that "countries with large 'high natural entry' industries have a strong entrepreneurial culture and select low entry regulation" – if legal origin is correlated with strength of entrepreneurial culture as well as with regulation, the instrumented variable might still be endogenous.

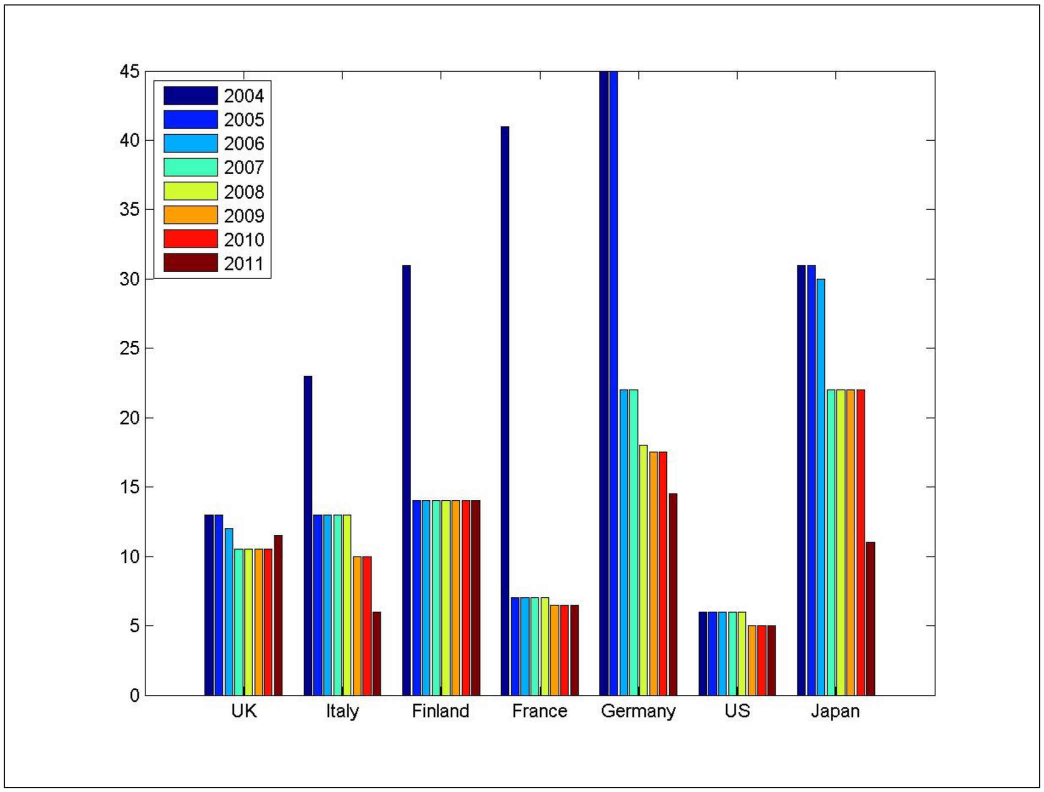

Figure 4-2: Time Needed to Start a Business, Doing Business Indicators (World Bank)

cators, has stimulated policymakers to reduce such barriers; Djankov (2009) states that "every OECD high-income country but Sweden and the United States... [has] made entry regulation faster and cheaper or administratively simpler" since 2003 (p.187). Figure 4.2 illustrates this downward policy trend, plotting the time required to start a business for selected OECD countries, including the UK, between 2004 (when the harmonised data becomes available) and 2014; Table 4.1 shows the downward trend in paid-in minimum capital required, as a percentage of income per capita (Source, World Bank Doing Business Indicators). As these measures illustrate, the UK has been at the lower end of the OECD spectrum for PMR stringency since 2004. Moreover, it was an early starter, as the OECD indicators show. PMR stringency indicators for the network industries show the UK reforming as early as 1981 (Figure 4-3).[30] Indicators of regulation in retail and professional services are only available at irregular intervals since 1998,

[30] This indicator provides figures on the US only for 1998, 2003 and 2009 (1.98, 1.91 and 1.65 respectively).

	Finland	**France**	**Germany**	**Italy**	**Japan(Tokyo)**	**UK**	**US (NYC)**
2004	29.8	29.2	49.1	11.6	74.9	0	0
2005	29.3	0	48.8	11.2	74.9	0	0
2006	28	0	47.6	10.8	75.3	0	0
2007	27.1	0	46.2	10.4	0	0	0
2008	7.7	0	42.8	9.8	0	0	0
2009	7.4	0	42.2	9.7	0	0	0
2010	7.2	0	40.8	9.7	0	0	0
2011	7.9	0	41.9	10.1	0	0	0
2012	7.3	0	40.2	9.9	0	0	0
2013	7	0	39	9.7	0	0	0
2014	7	0	37.8	9.8	0	0	0

Table 4.1: Paid-In Minimum Capital, percentage of income per capita. Doing Business Indicators. Source, World Bank

	Finland	**France**	**Germany**	**Italy**	**Japan**	**UK**	**US**
1998	2.862	4.500	3.402	4.350	3.533	3.380	na
2003	2.862	3.757	3.376	3.850	2.313	2.151	2.000
2008	2.886	3.805	2.876	4.064	2.313	2.180	1.760
2013	2.862	2.638	2.710	3.152	2.379	1.793	na

Table 4.2: Indicator of Regulation in the Retail Trade, OECD

but these also show UK amongst the most deregulated of the OECD group and continuing on the downward trend between 1998 and 2013 (Tables 4.2 and 4.3). Nicoletti and Scarpetta (2003) point out that the differing pace of reform across OECD countries during the 1980s and 1990s led to a divergence in the regulatory policy landscape between these countries. Crafts (2012) draws attention to this stylized policy fact as a potential explanation for the reversal of UK economic decline relative to its continental peer countries, primarily France and Germany; during the post-war era, UK productivity growth failed to keep pace with growth in these countries, but since the 1980s this gap has closed.

	Finland	**France**	**Germany**	**Italy**	**Japan**	**UK**	**US**
1998	0.495	2.188	4.276	3.906	2.484	1.323	na
2003	0.615	2.198	3.031	3.552	2.255	0.865	1.354
2008	0.714	2.448	2.818	3.021	2.099	0.724	1.354
2013	0.620	2.344	2.651	2.099	2.120	0.724	na

Table 4.3: Indicator of Regulation in Professional Services, OECD

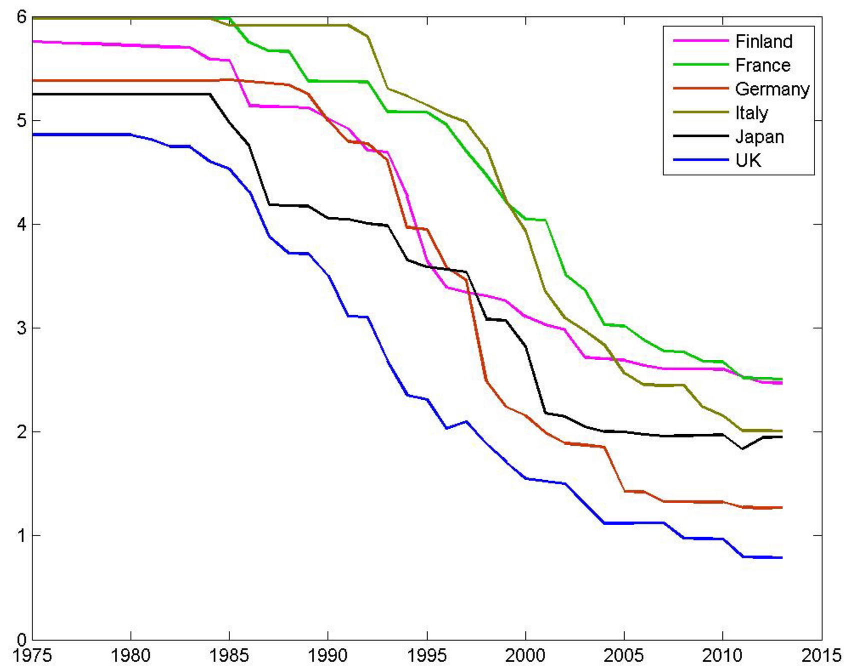

Figure 4-3: Product Market Regulation Indicator, Network Sectors (Energy, Transport and Communications). Source, OECD.

Labour Market Regulation

Following Botero et al. (2004, p. 1339), labour market regulation (LMR) signifies "laws and institutions intended to protect the interests of workers". In addition to certain civil rights protections, it includes employment law, collective relations law, and social security. Such regulation should theoretically correct labour market failures that lead to the extraction of rents by employers at the expense of employees, resulting in inefficiency and misallocation of welfare.[31] Every OECD country intervenes in the labour market in an attempt to rule out such failures; their correction should in theory improve welfare and productivity simultaneously. However, the regulations themselves may introduce frictions, and the focus of this chapter is ultimately on those and their potential growth effects. The practical impact of LMR on market outcomes depends also on how legislation, contracts and agreements are interpreted and enforced by the authorities responsible, as well as how compliance is monitored. This enforcement factor is not static over time and may itself respond to other determinants. Unfortunately no time series measures exist of regulatory enforcement quality for OECD countries (certainly not for the UK over the 1970 to 2009 period) so this dimension of the problem cannot easily be examined empirically.

Labour market regulation is a complex body of legislation with numerous and diverse potential impacts on incentives at the microeconomic level. Again, the theoretical direction of the growth effect of labour market regulation is ambiguous. It may be that employment protection legislation (EPL) increases investment in skills due to increased job tenure, leading to higher productivity growth via human capital accumulation (Damiani and Pompei 2010; Belot et al. 2007). On the other hand, higher regulation raises the costs of labour adjustment leading to labour market inefficiency (e.g. Mortensen and Pissarides, 1994; Hopenhayn and Rogerson, 1993), and may pose a barrier to the adoption of new technology requiring new skillsets. LMR may also reduce productivity by affecting a firm's choice of projects – by increasing anticipated costs of labour adjustment, high hiring and firing costs may lead to the selection of lower risk, lower productivity projects as opposed to more radical innovations with higher associated risk

[31] "For example, employers discriminate against disadvantaged groups, underpay workers who are immobile or invest in firm-specific capital, fire workers who then need to be supported by the state, force employees to work more than they would wish under the threat of dismissal, fail to insure workers against the risk of death, illness or disability, and so on." (ibid.)

(Saint-Paul 2002; Bartelsman et al. 2004).[32] Another productivity dampening effect is the potential for workers to increase absenteeism or reduce work effort due to the lower threat of dismissal. For more discussion of the theoretical literature on how regulation may affect labour market outcomes and hence productivity, see Bassanini et al. (2009, pp. 358-361).

In terms of the model in Chapter 2, where productivity growth is modelled as responding systematically to innovative activity z_t, which is in turn discouraged by the penalty variable τ - when τ is characterised as regulation and z is thought of as entrepreneurship (which certainly includes entry), we expect z to be discouraged by the prospect of labour market frictions encountered during firm operation; the future returns (at $t+i$, $i>0$) to innovation generated through z_t would be reduced by the costs and uncertainty generated by labour market regulation. This causal mechanism – from an increase in regulation to a decrease in productivity growth – is integral to the model data generating process. Therefore if in fact (i.e. in some alternative 'true' model) LMR increases productivity growth rather than decreasing it, this model should fail to explain the productivity experience of the UK and should be rejected by the test in Chapter 5.

In this section some empirical papers looking at the impacts of labour market regulation are reviewed. Though it examines possible explanations for labour market regulation rather than focussing on its effects, we start with the study by Botero et al. (2004). Not only is it a seminal paper in the aggregate quantification of such regulations, but it illustrates the potential for reverse causality in the country-level regression literature. Here certain variables are claimed as determinants of regulation (such as national income) which in other studies are thought to be explained by regulation.

Botero et al. 2004 investigate the determinants of labour market regulation, attempting to distinguish in the data between three theories of institutional choice that they term "efficiency theory" (public interest theory), "political power theory" (public choice theory), and "legal theory". Legal theory explains regulation as a result of legal tradition: common law countries favour markets and contracts, while civil law countries favour regulation and state ownership (Aherling and Deakin, 2007). The authors collect data on labour market regulation for 85

[32] For cross-country evidence that EPL hampers the adjustment process of productivity and employment after shocks, see Burgess (2000) and Caballero et al. (2004).

countries in 1997, creating an overall index of employment law which is the major contribution of the paper.[33] This index is then regressed using OLS on various potential determinants thought to be independent, including per capita income, average years of schooling, union density, a measure of political leanings of government averaged over time, and proxy measures of legal origin, for the cross-section of countries. The test of the efficiency theory hinges on whether or not a negative, significant association can be found between income per capita and labour market regulation: "rich countries should regulate less because they have fewer market failures".[34] Since the results show no significant relationship between income and employment protection, the authors reject the efficiency theory. This conclusion is not straightforward, however; various hypotheses are consistent with the finding of a limited statistical relationship between GNP per capita and LMR. In general the study suffers from a lack of identification, as well as many of the criticisms noted for cross-country growth regressions in Section 4.4.1. The authors acknowledge that "the efficiency theory is too broad to have strong implications for the extent and consequences of regulation, and as such is difficult to reject." (p.1343)

Other results suggest that labour regulation is negatively associated with lower workforce participation and youth unemployment, which "is most consistent with the political view that the privileged and older incumbents support more stringent labor laws" (p.1378), in support of e.g. Blanchflower and Freeman (2000). They point to an inconsistency with the efficiency theory here which ought to predict better labour market outcomes as a result of labour market regulation. Again, these are not the only conclusions one could draw from their results, particularly as there is no time series dimension. The idea that the dependent variables are "consequences" of the regulation of labour is not demonstrated. They attempt to instrument labour market regulation in these regressions using legal origins.[35] However, legal origins (as observed by Klapper et al., 2006) may be correlated with omitted variables in the first step regression making the instrument endogenous in the second step. If legal origins is associated some third unobservable factor (like cultural attitudes to entrepreneurship, for instance) that

[33] The index reflects "the incremental cost to the employer of deviating from a hypothetical rigid contract, in which the conditions of a job are specified and a worker cannot be fired" (p.?)

[34] The logic of this is dubious, particularly in a cross-section with no time variation. A positive correlation due to an effective use of past regulation to neutralise market failures, providing a well-functioning market place and hence leading to better economic outcomes, is also consistent with efficiency theory.

[35] They find a statistical association between legal tradition and labour market regulation, with common law tradition associated with a less regulated labour market than civil law.

is correlated with both regulation and the dependent variable, then the regression is still poor (Bassanini et al. 2009).

In general the empirical literature does not offer a firm consensus one way or another on the direction of impact of LMR on economic growth or on employment (Frontier, 2012). DeFreitas and Marshall (1998) conduct an industry-level study (manufacturing only) for a sample of Latin American and Asian countries, finding that increasing the stringency of EPL reduces labour productivity growth. However, studies of OECD countries by Nickell and Layard (1999) and Koeniger (2005) point to a weak but positive effect of raising the stringency of EPL on both TFP growth and R&D intensity.

Di Tella and MacCulloch (2005) examine the impact of survey-based indices of hiring and firing regulations on labour market outcomes for 21 OECD countries between 1984 and 1990. The regulatory indicators are based on the Global Competitiveness Report (World Economic Forum), which surveys groups of business managers on the labour market conditions they face. Estimating a dynamic panel with fixed time and country effects, they find that higher labour market flexibility is positively associated with the employment rate and labour force participation. Their estimates suggest that the difference in employment rates between France and the US would decrease by 14% if France were to reduce regulatory strictness in the labour market to the US level. These results are in line with the earlier conclusions of Lazear (1990), who found in a panel of 22 developed countries that severance pay and required notice periods were positively related to unemployment rates. The implication is that the strictness of such regulations (or perceptions of it) do affect the hiring and firing decisions of firms.

Bassanini et al. (2009) use country-level data on EPL and industry-level productivity data for 11 OECD countries and 19 industries, 1982-2003, arguing that the impact of EPL (fixed at the country level) is likely to vary for different industries within the same country.[36] The premise for their difference-in-difference approach is as follows: "If reforms of dismissal regulations have an impact on productivity, it will be greater in industries where, in the absence of regulations, firms rely on layoffs to make staffing changes, rather than in industries where

[36] The data used for industry-level TFP are taken from Inklaar et al. (2008), and indicators of EPL are the OECD indicators (OECD, 2004): index of dismissal for regular employment, index for temporary contracts, and index on additional legislation for concerning collective dismissals. The majority of their paper focuses on the results for the index of dismissal for regular employment.

internal labour markets or voluntary turnover are more important." (p.352) The distinction is between industries for which EPL is binding, and those for which it is has no practical 'teeth'. The latter is the control group. The approach assumes that the differences in TFP growth between EPL-binding industries and other industries is a function of the level of (or the change in) the index of EPL. Differencing removes fixed effects common to both groups from the analysis. Additional control variables include the productivity of the industry productivity leader and the distance from frontier. Their estimates suggest that mandatory dismissal regulations in OECD countries reduce TFP growth in industries with a high 'natural' rate of dismissal (as proxied by the US rate), to a disproportionate degree. This result is robust to sensitivity analysis surrounding the indicators and control variables.

However, they note various political economy arguments predicting causality from TFP to regulations. There may be political pressure to protect jobs during a downturn, leading to a negative impact of economic circumstances on the level of EPL; conversely, some suggest that liberalisation reforms are more frequently and easily implemented during economic crises (Drazen and Easterly, 2001), implying a positive relationship. Either case could imply endogeneity bias. They claim to have controlled fully for this using country-by-time dummies, which will capture aggregate effects common to both control and 'treatment' groups (supposing that both groups experience these aggregate effects in the same way). A more serious potential problem is that EPL is actually caused by profits, since profits (or market power) are positively correlated with lobbying power. In this case, the relationship between growth and EPL might just be picking up a correlation between growth and lobbying power (perhaps highly correlated with the level of EPL). They therefore instrument EPL in the regression. Instead of simply using legal origin and dictatorship variables as instruments, which might either have a relationship with alternative institutional drivers of TFP aside from EPL or be long-term drivers of TPF in their own right, they interact these variables with the industry-level layoff propensity variable.[37] An additional time-varying instrument is the interaction of a political orientation variable (measuring a cabinet's distance from the political left) with the layoff propensity vari-

[37] "In fact, these interacted variables appear to qualify as valid instruments to the extent that we cannot think of any economic mechanism inducing an effect of legal systems or dictatorship spells on productivity that varies across industries as a function of layoff propensity without occurring through their effect on dismissal regulations. Obviously, the validity of our instrumental variable strategy crucially hinges on the validity of this latter statement." (p.380)

able.

The results of the instrumental variable estimation suggest that endogeneity is not a problem. Likewise when the lagged relative TFP variable is excluded from the right-hand side, the magnitude of the estimates is reduced but the same broad conclusions remain. Similar conclusions apply when labour productivity growth and aggregate TFP growth are the dependent variable, rather than industry-level TFP. In conclusion, this seems reasonably robust evidence of an impact of EPL on productivity. Their estimates imply that a one percentage point reduction in stringency of EPL for regular contracts will raise aggregate labour productivity growth by 0.14 percentage points. No similar effect is found from EPL surrounding temporary contracts, however, and they find no evidence for the idea that EPL reduces catch-up to frontier.

While Bassanini et al. (2009) look at the productivity effects of EPL, they do not distinguish between new and incumbent or small and larger firms. Millan et al. (2013) look at the impact of EPL on the smallest firm in a micro-econometric study of individual-level data for the EU-15 countries, 1994-2001, using a random effect binary logit model. EPL is measured using the OECD macro-level indicator. In this setup they find that EPL stringency negatively affects the hiring and firing decisions of firms with 1-4 employees (i.e. the probabilities of employing new workers and dismissing current workers are both reduced), reducing labour flexibility for this class of firm. They emphasize the scale disadvantage applying to small firms in complying with EPL, since hiring and firing costs constitute a bigger proportion of overall labour costs, and there is less potential to redirect underperforming workers into different roles within the firm.

Van Stel et al. (2007) look at the impact of regulation on nascent entrepreneurship (the proportion of the adult population "actively involved" in starting a new venture) and at the conversion of nascent entrepreneurship into young entrepreneurship (the proportion of owner/managers of a business under 42 months old) using GEM data, in an unbalanced panel of 39 countries for 2002-2005. Regulatory indicators are the World Bank Doing Business Indicators. They find that the rigidity of hours index and the rigidity of employment index have a negative and significant impact on nascent entrepreneurship rates (both 'opportunity' and 'necessity' entrepreneurship). Of these, the rigidity of employment index has a significant negative impact on the young business rate. They do not find a strong effect of entry regulations on nascent or young entrepreneurship rates, however, except in the case of the minimum capital

	Finland	France	Germany	Italy	Japan	UK	US
1970	5.4	6.6	6.7	6.3	2.1	3.4	5.7
1975	5.9	6.0	6.7	6.2	2.1	3.2	2.2
1980	5.9	6.1	6.7	5.9	2.0	3.3	2.3
1985	6.2	6.2	6.7	5.9	1.9	3.2	2.3
1990	6.3	6.2	6.5	5.8	2.8	2.8	2.3
1995	6.5	6.6	6.4	6.5	2.5	2.8	2.5
2000	6.7	5.0	7.1	6.5	3.5	3.1	2.8
2005	5.2	4.5	6.1	3.5	1.5	1.5	0.9
2010	4.4	4.1	4.6	3.5	1.7	1.7	0.9

Table 4.4: Fraser Institute Labour Market Score, Inverted. Higher score signifies higher regulation

	Finland	France	Germany	Italy	Japan	UK	US
1985	2.786	2.591	2.583	2.762	1.702	1.032	0.257
1990	2.786	2.341	2.583	2.762	1.702	1.032	0.257
1995	2.452	2.341	2.679	2.762	1.702	1.032	0.257
2000	2.310	2.341	2.679	2.762	1.702	1.198	0.257
2005	2.167	2.468	2.869	2.762	1.702	1.198	0.257
2010	2.167	2.385	2.869	2.762	1.369	1.198	0.257

Table 4.5: Employment Protection Legislation Indicator, Strictness of Regulation over Individual Dismissals, Regular Contracts. OECD

requirement.

Policy Trends in Labour Market Regulation

Labour Market Regulation (LMR) has not displayed such a strong downward trend across the OECD, but the level in the UK as proxied by the Fraser Institute Overall Labour Market Score has fallen over the period, being already low relative to its European counterparts (Table 4.4; this table shows the inverted Labour Market 'Freedom' score, so that higher numbers indicate more regulation). The fall in this composite index for the UK is mainly driven by the reduction in frictions arising from centralised collective bargaining, hours regulations, and mandated cost of hiring workers. Other components of the overall indicator (firing costs and mandated cost of worker dismissal) have remained relatively stable over the period or even increased. This is clear from the OECD EPL time series measures; these focus on regulation around dismissals only, which seems to have moved little in the UK since 1985 (Table 4.5).

Aggregated Measures of Regulation and Growth

For a panel of 135 countries in varying stages of development between 1993 and 2002, Djankov et al. (2006) regress annual percentage growth in GDP per capita on indicators of business regulation and a set of controls and the initial level of income. Business regulations are measured by the World Bank Doing Business Indicators, which are averaged together to obtain an overall [0,1] score.[38] Finding a negative correlation between the strictness of business regulations and growth, they note that this could support three contrasting causal mechanisms: i) less burdensome regulation increases growth, ii) more growth frees up income to dispose on improving the regulatory environment, or iii) this is a spurious link due to the correlation of both regressand and regressor with a separate omitted variable. They therefore instrument regulation with a country's legal origin and various other country characteristics relating to geography and culture. The positive correlation of business regulation with growth remains in this formulation, and they test the instruments' exogeneity using over-identification tests, though the argument for the strength of the instrument is purely intuitive. They find further that moving from the highest quartile to the lowest in terms of regulatory burden increases average annual growth by 2.3%. The paper is vulnerable to many of the criticisms listed in Section 4.4.1; the most serious issue for our purposes is the lack of identification in the regression model, which the IV strategy does not resolve.

Gorgens et al. (2005) also investigate the relationship between an aggregate regulation measure and growth in an unbalanced panel of 123 countries for 1970-2000. In a non-linear fixed effects model with controls, growth rates are regressed on regulation as proxied by the Fraser Institute Economic Freedom index using system GMM (Blundell and Bond, 1998), where regressors are instrumented with their lags to control for endogeneity. The finding is that for high income countries, the level of regulation is negatively related to growth, but deregulation is most growth-enhancing for middle-income countries with a middle stock of regulation. For

[38] These indicators calculate (based on objective analysis of legislation and on interviews with experts) the relative burden imposed by regulation in seven areas: starting a business, hiring and firing workers, registering property, access to bank credit, protection of equity investors, legal enforcement of contracts, and closing a business. Thus both product market entry regulation and labour market regulation are covered, as well as capital market dimensions (outside the scope of this thesis). The country rankings in each of these areas are averaged by the authors and normalised to a zero-one interval to give an overall indicator of regulatory burden at the country level, where higher scores indicate lower burden.

low income countries, deregulation has little effect on growth.

One objection to the use of the overall EF score to proxy regulation is that, as a measure of economic freedom, it includes indices of size of government, of monetary policy predictability, of stability of property rights or the legal system – many distinct factors, some of which may be reasonably stable for the UK and other little regulated or high income countries over the sample period, or which may have time series profiles contrasting with the regulatory components of the index. The overall economic freedom score is perhaps too highly aggregated for the impact of regulation on growth to be distinguished from other policy trends; certain components of the index may offset or reinforce each other, perhaps reducing or magnifying the net effect. Certainly economic freedom and regulatory burden are not an identical concepts, though they may be related.

Structural Modelling Approach, Regulation and Growth

This section deals briefly with the macroeconomics literature in which the quantitative implications of policy reforms are investigated within a calibrated structural model. By 'structural' is meant sets of simultaneous relationships between macroeconomic variables derived from micro-foundations, which are then solved to obtain general equilibrium behaviour of the endogenous variables as a function of exogenous variables only (generally speaking these are the shock processes); i.e. DSGE models. These models often treat product market and labour market regulation together.

An influential paper on the macroeconomic effects of regulation is Blanchard and Giavazzi (2003). They derive a model in which both product market regulation and labour market regulation affect the number of firms in the goods market, as well as employment and the real wage, with interaction effects between the two types of regulation. Work in a similar vein is Everaert and Schule (2008), who use the IMF Global Model calibrated to the EU to examine the impact of synchronising structural reforms, both across product and labour markets and across countries within the EU. Likewise, Gomes et al. (2011) use the Euro Area and Global Economy model (EAGLE), a multi-country New Keynesian DSGE model, to analyse the impact of structural reforms on macroeconomic aggregates in EU countries. In these models, regulatory reforms are treated as reductions in price and wage mark-ups in labour and product markets.

Cacciatore et al. (2012) examine the short- and longer-run macroeconomic impacts of labour and product market reforms in a similar New Keynesian DSGE model of a small open economy, calibrated to the Euro Area as of 2007. The addition of search and matching frictions in the labour market allow hiring and firing costs to be modelled in a less reduced-form fashion. In practice the reform exercise abstracts from the stochastic features of the model, simulating the transition from one steady state to the post-reform steady state. None of these models puts explicit focus on the role of regulation in the innovation process; macroeconomic gains occur in general through reductions in markups which lower product and labour market slack, stimulating employment and investment.

Poschke (2010) looks at the impact of administrative entry costs on aggregate productivity in a DSGE model with heterogeneous firms, an extension of Hopenhyan (1992). On entry, firms have a choice between more and less advanced technology; in the model, entry costs reduce the marginal incentive to invest in more advanced technology since they reduce competition. Firms optimise with respect to a parameter on entry (corresponding to the type of technology) on which their stochastic productivity experience subsequently depends, subject to the entry cost they face. The sunk cost of entry increases with the expected productivity of their chosen technology. This, together with the endogenous exit of underperforming firms, leads to a stationary productivity distribution for firms, in spite of turnover among firms themselves. These firms are intermediate goods producers in a monopolistically competitive environment; as in Blanchard and Giavazzi (2003), the substitutability of intermediate goods in final production increases with the number of firms producing them. The model is calibrated to the US and used to simulate the new static equilibrium of TFP in response to policy experiments (the calibration is based on 1997 data). The paper investigates whether changes in entry costs, with all other US parameters held constant, can account for part of the TFP differential between the US and several European countries. Data on entry costs are taken from Djankov et al. (2002) and TFP is calculated following Inklaar and Timmer (2008).

When entry costs are raised from the US to the German level (c. 30% of GDP per capita), the difference between US and German TFP is reduced by about one third; this is a large impact, though it is about one third of the impact in Barseghyan (2008). In the model this occurs because fewer firms enter in general equilibrium, which reduces the substitution elasticity among differentiated goods; i.e. this captures a reduction in competition. This increases mark-ups while decreasing the market share of high productivity firms, since low productivity firms survive for longer under increased product differentiation. The incentive to invest in high productivity is therefore eroded. Since the equilibrium wage is also reduced (otherwise the increase in administrative costs would make entry unprofitable), this also reduces the exit threshold for inefficient firms. Thus the average productivity for the marginal firm is lower.

The model's performance is judged on whether it can generate similar features to those found in the data (i.e. a matching methodology); while the model generally produces statistics that appear 'close' to the target stylized facts when tabulated, there is no attempt to test the model formally against the data. Of course there is no time series component to the analysis and no claims are made about the model's ability to 'fit' the historical data econometrically – indeed there may be little interest in doing so. This is a quantitative investigation of the implications of a set of hypotheses formalised in a DSGE model, using a 'calibrationist' approach (Canova, 1994; see Chapter 3). The implications are interesting for policy and it is enough that they do not seem (impressionistically) at odds with observed features of the data.

4.4.4 Tax and Growth

There is a large body of normative work on welfare-optimal tax rates, following Ramsey (1927). Since the emphasis in this thesis is positivist, this literature is given only a summary treatment. For a survey, see Golosov et al. (2007). The central result in a Ramsey-style model, a neoclassical exogenous growth model in which the savings rate is optimally chosen (Ramsey, 1928; Cass, 1965; Koopmans, 1965), is that the optimal capital tax rate is zero, with all revenue raised on the labour margin (Chamley, 1986; Judd, 1985). This is a second best welfare scenario, when revenue cannot be raised solely by non-distortive lumpsum taxation. Capital taxes reduce the rate of return to investment, distorting the intertemporal margin, whereas the decision to allocate time between labour and leisure is an intratemporal margin. The effects of a distortion to the intertemporal allocation of resources accumulate over time, with a compounding effect on the capital stock, while the taxation of the labour margin has a static effect.[39] This result

[39] Another way to see this is that the tax on capital causes the price of consumption in a future period T in terms of today's consumption to increase exponentially as T becomes large.

also holds in some endogenous growth setups (e.g. Lucas, 1990). Distortions to intertemporal margins may therefore carry a large penalty for growth and welfare. Note, however, more recent work by e.g. Kocherlakota (2010) ~ where information asymmetries lead to different results ~and Aghion et al. (2013a) who show that a zero capital tax is sub-optimal in a creative destruction model. Again we require some empirical basis on which to choose between normative analyses conducted within competing theoretical models.

Many theoretical models exist in which long run growth rates respond endogenously to tax policy reforms; again I do not spend long on these. See Myles (2009a) for an overview of this theoretical literature. In general, any spillover model in which diminishing returns to some type of knowledge capital investment at the firm level are overcome, via externalities, at the social level will imply higher long run growth when such investment is subsidised, provided that subsidies are financed by non-distortive taxes. This includes human capital externality models like Lucas (1988) and Romer (1990). Equally, tax rates that penalise research incentives by affecting the expected returns to an innovation (i.e. profit taxes) will lower the innovation rate ceteris paribus (e.g. Aghion and Howitt, 1992), though as emphasized in Section 4.3 there may also be opposing effects (tax rates may protect incumbents, raising innovation by reducing the business stealing effect; Acemoglu, 2008); these models can be constructed so that there is some ambiguity over the impact of taxes on growth.

When subsidies must be funded by other distorting tax instruments rather than a lumpsum tax, the net growth effect becomes more complicated. Some positivist simulation exercises in human capital-driven models yield different growth impacts for revenue-neutral capital and labour tax reforms. Lucas (1990) finds that setting capital taxes to zero and raising labour taxes correspondingly has little impact on long run growth, though the level of output responds significantly. However, Jones et al. (1993) find large effects on both the level and the growth rate from the same reform, as do King and Rebelo (1990) in response to a 10 percentage point increase in capital tax rates. The different results are due to differences in the model composition and calibration; in both cases human capital production is modelled with a physical capital input, whereas in Lucas (1990) the function only uses existing human capital and a time input. Thus the impact of taxation on growth depends crucially on the modelling of human capital formation – on the assumed inputs to that process and their tax treatment. Stokey and Rebelo (1995) analyse these models, also demonstrating that the calibration of certain parameters determine the extent of growth effects from tax reforms.[40]

Barro (1990) introduces another factor, modelling government spending as an input to production, financed by taxation. This input corresponds to government-provided public goods such as infrastructure. The reduction in the rate of return on private sector capital due to distorting taxation is overcome by gains from raising the public capital input. Zagler and Durnecker (2003) integrate this approach into a spillover model with a range of tax instruments on labour and intermediate inputs to final production, on the profits and R&D expenditures of monopolistically competitive intermediate goods producers (whose innovation activities are subsidised from savings), as well as on income and savings. The innovation rate depends on human capital. Taxes finance a public input to final production. The long run growth rate is a function of all these tax rates; the increased public good raises growth while taxes on R&D and savings reduce innovation and capital accumulation, respectively, while the impact of other tax rates is ambiguous. This positive effect of government-financed goods muddles the relationship between tax and growth in the data, complicating aggregate-level empirical work in this area.

In general, any endogenous growth model in which long run equilibrium growth rates respond to marginal investment decisions will imply certain policies surrounding the tax treatment of this margin. Taxes can distort important trade-offs, though the calibration of the model and functional forms assumed will determine the extent of the growth impact. These models often predict rather large effects of tax changes on growth which have generally seemed inconsistent with post-war growth experience of OECD countries (cf. Jones, 1995a). Many cite the apparent lack of correlation between steadily rising average tax rates and the unchanging long-run economic growth rate in the post-war OECD experience (Slemrod, 1995). Of course, such time-series correlations do not tell us anything about counterfactuals or causality.

To reiterate, in Chapter 2 the policy variable is modelled as stationary; tax policy is not assumed to affect the long run balanced growth path of productivity, which is modelled as an exogenous drift term. We do not look at changing the stationary long run level of taxes, but at how fairly persistent changes around the long-run level can have lasting effects on the level of

[40] They find the growth effect of reforms highly sensitive to factor shares, depreciation rates, the elasticity of intertemporal substitution and the elasticity of labour supply, but not so sensitive to the elasticities of substitution in production.

productivity, producing transitional growth episodes. Therefore it is really a 'semi-endogenous' growth model in the style of Jones (1995b).

Empirically it is difficult to disentangle the historical relationships between different tax instruments and growth, as they are often mutually offsetting; regressions with tax instruments on the right hand side and growth on the left are usually vulnerable to criticisms of endogeneity and are certainly not identified. Therefore while they may provide evidence of association, little can be concluded as to causality (see Section 4.4.1). See Myles (2009b,c) for comprehensive surveys of empirical work on the tax-growth relationship using aggregate and disaggregate data, respectively. Some country-level studies on tax and growth are discussed below, primarily for their relevance to data choice in Chapter 5. However, following Myles (2007), the stance taken on this literature is that "Ultimately it can only be concluded that these growth regressions have provided little in the way of insight into the sources of economic growth or the link between taxation and growth." (p.3) Therefore it is not used to calibrate the parameters b_1 or c_1 in Chapter 5.

Many cross-country growth regressions include the overall share of tax revenue in GDP as an explanatory variable.[41] This measures the national average tax rate. While theory suggests that marginal tax rates distort individual incentives so as to reduce investment and other important variables, implying a negative impact on growth, the overall effect of tax revenue on growth is ambiguous. Endogenous growth models with public goods as productive inputs imply that tax revenue (correlated through the government budget constraint with the public goods that it finances) may indirectly imply a positive relationship between average tax rates and growth. The force of this positive tax-growth mechanism will not be monotonic if there is an underlying Laffer curve such that tax rates above or below the optimum reduce overall revenues and hence public spending. Therefore theory cannot unambiguously identify the coefficient in this relationship between average tax rates and growth (it will depend on where tax rates are relative to their optimum).

More to the point, negative growth effects arise in theory not from the average tax rate but from the marginal tax rate, i.e. the proportion of income earned through an additional unit of some activity or investment that will be confiscated. Generally for OECD economies the

[41] Much of this discussion follows Myles (2009b).

average and marginal tax rates are not the same, due to progressivity in the tax schedule; for a progressive tax system, the marginal tax rate is above the average rate at every income level. Since the marginal rate changes at the threshold between different income brackets, calculating the appropriate national level of the marginal rate for personal income taxes is difficult, made more so by exemptions or special rates for different types of income. For corporation tax, the picture is further complicated by accelerated depreciation allowances for different types of capital spending and other tax breaks, such as the R&D tax credit discussed in Chapter 6. Some studies (Koester and Kormendi, 1989; Easterly and Rebelo, 1993) attempt to calculate an 'effective' marginal tax rate at the economy level, but whether these capture cross-country differences in tax design consistently is usually controversial. At any rate, due to the inherent difficulties in measuring marginal tax rates the average tax rate is still widely included as a regressor.

Many earlier studies in the tax-growth literature do not account for endogeneity bias in their estimates (Engen and Skinner, 1996). Tax is a highly politicised area and rates certainly respond to political pressures, which in turn can be caused by the state of the economy. Slemrod (1995) notes that government expenditure responds to country-level political preferences, and that the income elasticity of demand for public goods is above one (Wagner's Law) – i.e., demand for public goods increases with development – implying reverse causality in the average tax–growth relationship. These regressions lack structural underpinnings, depriving their estimates of a clear interpretation (there are no identifying restrictions). Overall, Myles (2009b) concludes that "This is an area of research in which no progress appears to have been made." (p.33) In light of these issues, I restrict the following brief review to more recent studies in which endogeneity is addressed and marginal rates are employed, and focus on empirical work establishing a link between tax rates and entrepreneurship.

Linking Tax to Entrepreneurship

There is some empirical evidence for the hypothesis that taxation reduces entrepreneurship through incentive effects, though other studies reject it. Theoretically, the impact of marginal tax rates on the aggregate level of entrepreneurship is ambiguous, depending on the risk attitudes of potential entrepreneurs (Gentry and Hubbard, 2000). Risk averse individuals will be more inclined to undertake uncertain entrepreneurial ventures when tax schedules are more progressive (i.e. when the marginal tax rate is higher relative to the average rate), since a more redistributive tax regime acts as insurance against failure; this would imply a positive relationship between marginal tax rates (or tax progressivity) and entrepreneurship (Domar and Musgrave, 1944). Progressive taxes on income or profits have been termed “success taxes”, since the entrepreneur will face higher rates when successful than if he fails. However, for a risk neutral entrepreneur when loss offsets are imperfect, success taxes will reduce entry (Gentry and Hubbard, 2000).[42]

Another channel through which tax rates on businesses (or the interaction between these and other tax rates) might lead to higher entrepreneurship as measured by self-employment is tax avoidance – if tax rates on business profits are lower than on wage income, individuals will move into self-employment. Some studies look at how different tax instruments affect entrepreneurship levels through their effects on risk-taking (for references, see Baliamoune-Lutz and Garello, 2014, p. 171). Tax instruments may also affect access to finance for start-ups (Gompers and Lerner, 1999; Bruce and Mohsin, 2006); the empirical consensus is that venture capital funding is negatively related to tax rates. Asoni and Sanandaji (2009) propose a theoretical model in which progressive taxes reduce the average quality of the firm, though entrepreneurial entry rates increase.

In summary, the theoretical channels through which tax rates might affect entrepreneurship rates are as numerous and complex as the regulatory channels; again the issue of which theory should be preferred is an empirical one, and again distinguishing between different theories in the data is difficult. Baliamoune-Lutz and Garello (2014) provide a table summarising the samples, tax regressors and qualitative results of recent empirical work on entrepreneurship and taxes for OECD countries (2014, Table 1, p. 169); the take-away point is that the sign and magnitude of the estimated effects differs broadly both across countries and within countries or groups of countries for different studies.[43] Two time series studies for the UK illustrate this: Parker (1996) finds a positive impact of marginal tax rates on growth, while Robson (1998) finds no effect.

[42] Perfect loss offsets allow all losses to be deducted from future tax liabilities.

[43] This suggests that assuming homogeneous coefficients in a panel estimation would be inappropriate.

Baliamoune-Lutz and Garello find that tax progressivity for above-average income brackets reduces GEM measures of nascent entrepreneurship in aggregate panel data for 15 OECD countries between 2000 and 2008. They regress nascent entrepreneurship on tax rates, tax progressivity and a range of controls. Observing the potential for two-way causality between entrepreneurship and the tax variables, since tax reforms may be a policy response to poor observed entrepreneurship outcomes, they use the Arellano-Bond (1991) dynamic GMM estimator. The instruments pass exogeneity tests (tests ruling out second order autocorrelation and tests of overidentification restrictions).

They then derive two progressivity variables: progressivity_1 is the difference between the marginal tax rate applying at 100% of average earnings and the marginal rate applying at 67%, and progressivity_2 is the difference between the marginal rates at 167% and 100% of average earnings. Progressivity_2 is significantly negatively related to entrepreneurship, while progressivity_1 is not.[44] Hence, consistent with Gentry and Hubbard's micro-analysis on US data (2000, 2004), their results show that tax progressivity decreases nascent entrepreneurship for those who start with higher incomes, while it increases it for those with low to average incomes. They find no robust impact from average or marginal tax rates alone. The policy implication is that reducing tax progressivity for the income bracket between 100% and 167% of average earnings stimulates nascent entrepreneurship, while increasing it at the lower end of the income distribution does the same.

They note that the impact of this reform depends in practice on reforms to other factors in the entrepreneurship decision, such as regulatory costs. The entrepreneur responds to the tax schedule "*in its entirety*" (their italics) and deriving the effective tax rate is extremely challenging. In their concluding remarks they speculate that "it is not clear that governments should take the opposite direction and engage in positive discrimination in favour of start-ups or new businesses. It is possible that the best strategy would involve more fiscal neutrality. Low progressivity, or even a flat tax, might be part of such a strategy but it is also important to reduce the global fiscal burden and start-up costs." (p.185).

Corporation taxes have also been linked to entrepreneurial incentives in empirical studies.

[44] This result is robust to the use of average rather than marginal rates in calculating the progressivity indicators.

Djankov et al. (2010) derive comparable effective corporate tax rates for 85 countries of different income levels in 2004, regressing investment and entrepreneurship on these tax rates for the cross-section. Entrepreneurship is measured by cross-country indicators of business density and formal entry, developed from the World Bank's Entrepreneurship Survey which gathers data on business registration.[45] They recognise that these measures exclude informal entrepreneurship, while including incorporation for administrative rather than start-up purposes. They attempt to rule out spurious correlations by adding controls: lagged per capita GDP, tax evasion, institutional quality, entry and labour market regulation, inflation, seignorage and trade openness. Across a variety of specifications they find a significant, negative effect of corporate tax rates for the top income band on both business density and entry rates, as well as on fixed capital formation in manufacturing (though not in services) and foreign direct investment: "in these new data, corporate taxes matter a lot, and in ways consistent with basic economic theory." (p.59)

Da Rin et al. (2011) look at the impact of lagged average effective corporate tax rates for 17 EU countries, 1997-2004, on formal incorporation rates at the country-industry level, in a panel regression with fixed country and time effects for various non-linear specifications. Acknowledging potential endogeneity of tax rates in the regression due to political economy arguments, taxes are instrumented with indicators of government ideology, individuals with veto power in government, the degree of government fragmentation, government stability and election dates; also, a pro-business policy indicator is included as a control in all specifications.[46] They conclude that corporate tax rates reduce entry rates, though only when tax rates are below a threshold level. This holds across different specifications and for different measures of effective tax rates, and for both OLS and GMM-IV estimation.

[45] Business density is the total number of registered limited liability corporations per 100 members of working population in 2004, and the rate of new business registration is new registrations as a proportion of total registrations, averaged between 2000 and 2004. The data excludes sole proprietorships, i.e. 15.1 million businesses in the US as of the time of publishing; however, their tax regime is different so their inclusion would inappropriate.

[46] "Our approach to identification is based on the idea that structural and behavioral characteristics of the political system are likely to affect firms' entry rates only indirectly, that is through corporate taxation, once other policies to business creation are appropriately controlled for." p.1056.

Dynamic Scoring

Before proceeding to empirical work in Chapter 5, further motivation for the approach taken in this study is provided by the UK government's recent exercises in dynamic scoring (HMRC, 2013; 2014).[47] These papers represent the first efforts of a UK government to model the dynamic macroeconomic impacts of proposed tax reforms using a calibrated computable general equilibrium (CGE) model. CGE models of this type are used by the US Congressional Budget Office to analysis the effects of tax cuts (e.g. Foertsch, 2004; Gravelle, 2010). The UK corporation tax exercise (HMRC, 2013) is based on the premise that, while reducing corporation tax rates represents a static cost to the exchequer in lost revenues, it implies dynamic gains through the stimulation of business investment via the reduction in the cost of capital, and transitional productivity growth which, by raising taxable profits, allow much of that cost to be recovered.

This exemplifies the stance of the coalition government elected in 2010 that growth is a key policy objective: "Corporation tax reductions [. . .] are central to the Government's drive to stimulate growth and investment through supply side reforms" (HMRC, 2013, p.5). It is also interesting in terms of the controversy it has generated, and for good reason. For a detailed discussion of the difficulties inherent in dynamic scoring exercises, see Adam and Bozio (2009) who point out that "dynamic scoring requires making numerous modelling assumptions and essentially guessing the parameters *for which no hard empirical evidence is available.* [. . .] This opens the door to large controversies if these guesses are made – or perceived to be made – in a politically biased way." (p.20, my italics). They go on to say that: "Proponents of tax cuts often argue that the economic effects are large. As noted earlier, health and safety regulations might be costly for businesses to implement, reducing profits, employment and tax revenue; or they might lead to a healthier and more productive workforce, with the opposite result. The nature and magnitude of these effects is likely to be exactly what proponents and opponents of regulations dispute. A body responsible for dynamic scoring is in effect asked to pass judgement." (ibid.) Of course sensitivity tests can be conducted around important parameters, but this amounts to an admission that the range of potential effects could be extremely large. Always the results depend on the causal assumptions of the model and its

[47] For an outline of dynamic scoring, see Mankiw and Weinzierl (2006).

calibration, the reliability of which is generally based on separate empirical work which, as we have seen, is often flawed in its methodology or interpretation.

The contribution of Chapter 5 is therefore to *test* a dynamic stochastic general equilibrium model in which certain tax rates and indicators of regulatory burden cause productivity growth, affecting it in a particular direction and with a particular magnitude, for the UK experience between 1970 and 2009. The magnitude of that effect is then *estimated* using indirect inference methodology, together with other coefficients in the model for which priors are not strong. The relationship between tax and growth in the model is fully identified and the output generated by this model, when bootstrapped, provides a distribution of counterfactual policy and growth experiences for the UK. Using the unrestricted auxiliary model outlined in Chapter 3 Section 3.2, the average of these model simulations can be compared to the historical data for closeness through the indirect inference Wald statistic. In this way, we see whether a model in which causality unambiguously runs from tax to growth is rejected as the data generating process for the UK experience.

4.5 Conclusion

This chapter has provided some motivation for the empirical work conducted in Chapter 5, locating the contribution within the broader academic literature. As a logical preface to the choice of data for the policy variable τ'_t in the next chapter, a notional definition for z_t was outlined following Wennekers and Thurik (1999). Thus entrepreneurship involves implementing new ideas in markets. If policy creates large frictions in this process then a proportion of innovative ideas will fail to be translated into productivity growth. Further, for entrepreneurship to drive productivity growth, markets must be competitive; an uncompetitive market offers little reward for entrants to implement new ideas or to exploit perceived opportunities, so entrepreneurship and competition go hand in hand. Finally, the rewards from implementing ideas in the market must be to a large extent appropriable by the entrepreneur or his household; taxes and compliance costs distort the marginal decision to engage in entrepreneurship.

In the context of the new endogenous growth literature we discussed theories in which entrepreneurs play a prominent role, particularly the knowledge spillover theory of entrepreneurship, which characterises the entrepreneur as the 'conduit' for spillovers from established firm R&D to economy-wide productivity. This theory recommends the removal of policy-induced 'barriers to entrepreneurship', including regulatory obstacles, excessive bureaucracy, taxes and labour market rigidities, all of which increase operation costs and uncertainty for the entrepreneur. Beyond this the growth policy recommendations depend on the calibration of various spillover parameters in the model; assigning magnitudes to these parameters is not straightforward. Ultimately the specific growth and welfare policy recommendations remain obscure in the absence of empirical estimation of these models.

The DSGE model presented in Chapter 2 is a testing vehicle for the prediction shared by several theories that policy barriers to entrepreneurship have important macroeconomic effects; in its relative simplicity it bypasses many of the operational issues which have prevented many other theoretical models from being taken to the data in a convincing way. In this chapter we argued for a focus on the model's implications for macroeconomic aggregates rather than on the literal accuracy of its microfoundations, so disavowing the homeomorphic modelling approach according to which a model should aim to be 'realistic' in every particular.

We also emphasized the theoretical ambiguity of the effects of many tax and regulatory policies on both entrepreneurship and on productivity growth, concluding in each case that the question is ultimately empirical. If the hypothesis embedded in the model states that regulation reduces short-run productivity growth, while the opposite holds in the 'true' model that produced the observed data, the false model will be rejected as the process underpinning the UK productivity experience when it is tested by Indirect Inference, since the power of that test to reject a false null is high (see Chapter 3). Importantly, the model is identified, ensuring that we are not testing a theory in which growth causes policy. As this review has shown, much existing empirical work cannot make the same claim.

Chapter 5

Testing and Estimating a Model of UK Growth Driven by Entrepreneurial (Dis)Incentives

In this chapter the model in Chapter 2 is set up to test the hypothesis that entrepreneurial activities drive productivity growth. More specifically, the model assumes that a temporary (though persistent) change in the policy environment surrounding entrepreneurial activities results in a permanent change in the level of productivity, implying a short run change in the growth rate. We see whether such a data generating process can accommodate the behaviour of productivity and output in the UK between 1970 and 2009. Though a shorter sample would offer a richer set of potential indicators of the policy environment faced by entrepreneurs, a longer time series dataset captures greater variation in policy behaviour within the UK. The 1970s reflect a policy regime in the UK in sharp contrast to the supply side reforms of the 1980s and 1990s, and its inclusion adds significantly to the variation in the sample data.

In Section 5.1 I describe the data used to identify the growth channel; Section 5.2.1 gives the test results for the calibration described in Chapter 2 as a benchmark; and Section 5.2.2 presents the results of the indirect inference estimation for this model.

5.1 The Policy Variable

The discussion in this section revolves around the choice of data for the policy variable τ'_t. First I reiterate what tau signifies in the theoretical hypothesis that we would like to test; then the data used for τ' in this chapter is described. To some extent this choice is dictated by constraints on data availability.

According to the model, the policy variable is a systematic driver of the level of productivity via the activities (z_t) which it either stimulates or discourages. Equation 2.53 derived in Chapter 2 is repeated here for convenience:

$$D \ln A_t = b_0 + b_1 \tau'_{t-1} + e_{A,t} \tag{5.1}$$

The data ascribed to τ'_t identifies the growth channel, since z_t itself is not included in simulations of the model; hence it drives the interpretation of the empirical results that follow in Section 5.2. Indeed, it determines which precise theory is being tested there.

Here we suppose that $b_1 < 0$, i.e. that τ'_t penalises the growth driving activity z_t. Therefore the variable τ'_t should reflect policies dincentivising the entrepreneurial activities ascribed conceptually to z_t in Chapter 4. It could in theory embrace any policy-related factor that reduces the expected return to those activities, or (equivalently) that raises the uncertainty attached to returns. τ'_t stands for the extent to which the returns from higher productivity resulting from z_t are not appropriated by the entrepreneur responsible for generating them.

In Chapter 4 we discussed some theoretical motivation for the choice of certain framework policy drivers of entrepreneurship, noting some ambiguity over the predicted direction of impact. Whether (or which of) these theories hold in the data is an empirical matter, and existing empirical work investigating them was also reviewed in the preceding chapter. We also discussed some empirical literature linking certain policies to productivity growth directly. Here the aim is to focus on policies which might target productivity via our conception of entrepreneurship; I limit the scope to tax and regulatory policies.[1]

[1] Since the possibility that our chosen policies target channels other than 'entrepreneurship' cannot be ruled out, other policies are investigated in Chapter 7 which are more easily tied to the R&D channel (and *not* to entrepreneurship), so as to provide an additional and complementary perspective. This is discussed further in the Conclusions, Chapter 8.

To reiterate, entrepreneurship is loosely defined here following the synthesis of the entrepreneurship literature in Wennekers and Thurik (1999) as the "ability and willingness [...] to perceive and create new economic opportunities [...] and to introduce their ideas in the market, in the face of uncertainty and other obstacles [...] it implies participation in the competitive process" (p. 46-47). Clearly this embraces diverse activities for which the policy-related incentives are numerous, interacting in complex ways at the micro level. Our aim is to find a time series that is long enough and frequent enough for the sample period, while being an appropriate proxy at the macro level to the policy environment in which entrepreneurs must exist.

Rich time series data on business environments, such as the World Bank's Doing Business indicators, have only been systematically collected in recent years; where pre-1990s data exist on the regulatory burdens surrounding business activities, they are patchy. The need to capture only aspects of the policy environment which lead to innovative business activity relates to Baumol's distinction between productive and unproductive entrepreneurship (Baumol, 1990). Excessive regulatory or tax burdens can lead to unproductive entrepreneurship as individuals divert energy to avoidance or evasion, or to lobbying for their removal. Hence their removal should stimulate productivity growth. On the other hand, the removal of regulatory disincentives or the introduction of subsidy programmes (i.e. negative burdens) explicitly designed to incentivise entrepreneurship may lead to business start-ups that are un-innovative and make no contribution to productivity growth, though they may reduce unemployment. For this reason, measures of new business creation or self-employment rates could be poor proxies for z_t, grouping both innovative and uninnovative start-ups or small businesses together, while only a subset of these generate productivity growth.

If z_t is productive entrepreneurship alone, τ_t' will ideally reflect incentives to productive entrepreneurship only, excluding any policies that incentivise the unproductive type. Some examples of what we would not want to capture in τ_t' would be the incentive, noted by Crawford and Freedman (2010), for an employee to become self-employed or for a self-employed person to incorporate purely for tax arbitrage purposes - since the activity undertaken is unchanged, there is no impact on productivity from changes in the incentives around its formal categorisation.

In practice, policy measures which enhance productive entrepreneurship in some individuals may simultaneously encourage unproductive entrepreneurship in others.[2] At the aggregate level the focus is on the net impact of such policies on growth. If the net effect of cuts in the regulatory and tax burdens identified as τ_t' is to persuade people into entrepreneurial activities which are less innovative or more risky (hence more likely to fail and result in wasted time and resources), the negative relationship between τ_t' and productivity growth that drives the model will be a flawed representation of the data generating process in operation. The proposed theory would be false and we would expect the model to be strongly rejected when it is tested. In other words, the issue is again empirical.

5.1.1 Data for the Policy Variable

A less aggregated measure of τ' is preferable. This minimizes the risk of different component indices offsetting one another within the overall index and so obscuring the policy conclusions. Therefore I have been parsimonious in selecting components to combine into the single policy index.

The UK index created for τ_t' falls into two parts: regulation and tax. On regulation, the focus (due to data range and availability) is on the labour market. I have selected two components from the labour market sub-section of the Economic Freedom of the World (EFW) indicators compiled by the Fraser Institute: the Centralized Collective Bargaining (CCB) index and Mandated Cost of Hiring (MCH) index. Of the labour market measures, these two components span the longest time frame. Each are measured every five years between 1970 and 2000, and annually thereafter until 2009. The original data source for the CCB index is the World Economic Forum's Global Competitiveness Report (various issues), where survey participants answer to the following question: "Wages in your country are set by a centralized bargaining process (= 1) or up to each individual company (= 7)."[3] The Fraser Institute converts these scores onto a [0,10] interval.

The MCH index is based on data from the World Bank's Doing Business project, and reflects "the cost of all social security and payroll taxes and the cost of other mandated benefits

[2] Perhaps morally suspect firms ('cowboys') enter the market, where before regulation screened them out; these businesses should not last long as consumers learn quickly to avoid them, but they increase uncertainty and asymmetry of information in the market place and so undermine the efficiency of the allocation process.

[3] The precise wording of this question has differed slightly for different years.

	CCB	MCH
MCH	0.797	1.000
TUM (inverted	0.899	0.764

Table 5.1: Correlation coefficients between Fraser Institute Labour Market Indicators CCB (Centralised Collective Bargaining) and MCH (Marginal Cost of Hiring) and Trade Union Membership as a Proportion of Total Working Population, inverted (TUM inverted).

including those for retirement, sickness, health care, maternity leave, family allowance, and paid vacations and holidays associated with hiring an employee" (Fraser Institute, 2009). These costs are also converted to a [0,10] interval, where zero represents a hiring process with negligible regulatory burden.[4] Thus labour market flexibility increases with both indices in their raw form. These [0,10] scores are scaled to a [0,1] interval in this chapter before being interpolated as follows.

Data on UK trade union membership (TUM) is available at an annual frequency from the late 19th century. Here TUM data for 1970 to 2009 is made quarterly using a quadratic three-point interpolation (estimated values average to annual values), and then divided by total employment (16+) to give a quarterly union membership rate on a [0,1] scale. The series is then inverted and used to interpolate both the CCB and MCH series via the Denton proportionate variant adjustment method (Denton, 1971).[5] It seems reasonable to use the unionisation rate to interpolate CCB and MCH as they should be highly correlated on theoretical grounds; we expect union membership to be greater when the bargaining power of unions to affect worker conditions is higher. Equally, increased protection of worker benefits should be correlated with a strong worker voice, usually represented by unions.[6] The correlations in the data bear this out; see Table 5.1.

The Denton method is applied to each of these series in conjunction with the inverted union membership rate. The method minimises a quadratic loss function subject to the constraint

[4] "The formula used to calculate the zero-to-10 ratings was: (Vmax - Vi) / (Vmax - Vmin) multiplied by 10. Vi represents the hiring cost (measured as a percentage of salary). The values for Vmax and Vmin were set at 33% (1.5 standard deviations above average) and 0%, respectively. Countries with values outside of the Vmax and Vmin range received ratings of either zero or 10, accordingly." (Fraser Institute, 2009).

[5] The series is inverted by subtracting it from one. Thus where before it represented the proportion of the working population belonging to a trade union, now a value closer to one implies a lower trade unionisation rate.

[6] Of course there are alternative theories predicting a negative correlation between MCH and union membership (the idea that unions are only needed when the government fails to represent the interests of workers directly) but the data indicate a positive correlation does indeed hold (see table X).

that interpolated values between existing data points of the low frequency series should average to those points. The interpolation is carried out for both level and first differences of y/x, where y is the low frequency series and x the higher frequency series (the union membership rate); the resulting series are very similar but first differences are smoother. I use the first difference output. The resulting quarterly series for CCB and MCH incorporate information from the unionisation rate. These interpolated series are inverted so as to represent a penalty rate, where a higher value indicates a more hostile business environment from the perspective of small businesses.[7] They are plotted below in Figures 5-1 and 5-2 against the scatter of low frequency data points (scaled to [0,1] and inverted (subtracted from one)). As the figures illustrate, neither interpolated series strays far from the original Fraser Institute score.

The interpolated and inverted CCB and MCH indicators are equally weighted together to give an indicator of labour market inefficiency; we label this the 'Labour Market Regulation' indicator (LMR) in what follows.[8] (See Figure 5-3)

Other types of regulation are not incorporated into τ'_t in this study. Not only are good quality measures largely unavailable spanning the full period under analysis but, as stated earlier, the inclusion of too many distinct series within τ'_t makes the policy interpretations of the test less clear. However, it is interesting to note the high positive correlation between the Fraser Institute measures of CCB and MCH and the OECD indicator of Product Market Regulation (PMR). These correlations are presented in Table 5.2.[9] This suggests that the LMR indicator may not be a bad proxy for product market entry regulation in the UK. We should not overstate the power of the LMR indicator to represent the regulatory landscape as a whole; environmental regulation and planning regulations are excluded, as is the impact of regulatory enforcement. Planning regulations in particular are thought to pose a serious barrier to UK

[7] Again, the inversion involves subtracting the existing values from one, so that where before a higher value indicated more 'freedom' from regulation, the value after inversion measures the 'burden' of regulation.

[8] A full measure of regulatory burden in labour markets would also reflect all areas of employment protection legislation including costs from firing (see e.g. Botero et al., 2004), but data availability is a constraint. Correlations of our LMR indicators with OECD measures of EPL from 1985 for the UK are actually negative; our indicators do not fully capture the increases in dismissal regulation over the period and thus may slightly overstate the extent to which the UK labour market is 'deregulated'; however, the strong decline of collective bargaining and union power over the period represents the removal of significant labour market friction.

[9] These correlations are between the raw EFW measures and the inverted OECD measure – for all measures a higher value indicates less regulation; of course had we inverted the EFW measures and left the OECD measure uninverted, the correlations would be the same.

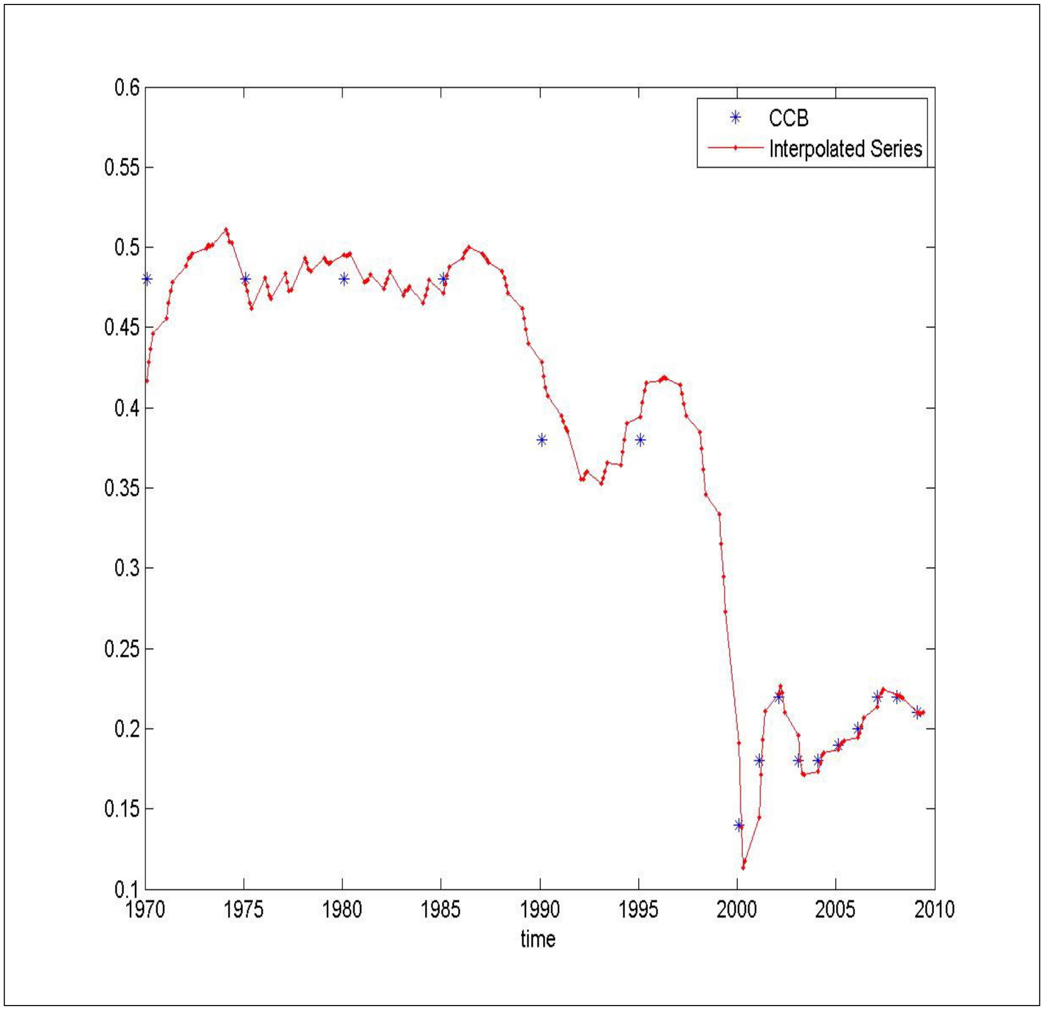

Figure 5-1: Inverted Fraser Institute Centralized Collective Bargaining (CCB) Score; Original Points and Interpolated Series.

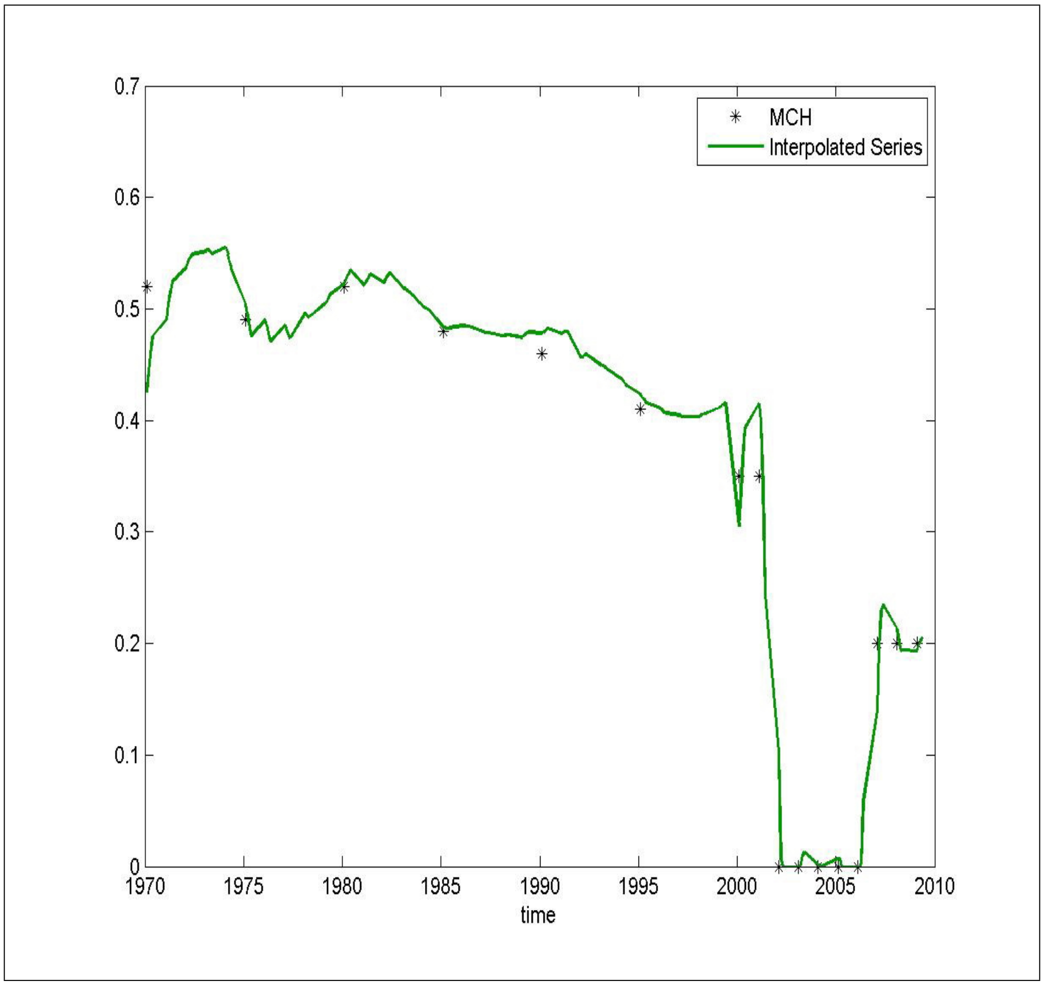

Figure 5-2: Inverted Fraser Institute Marginal Cost of Hiring Score; Original Points and Interpolated Series.

	OECD PMR (inv)
CCB	0.947
MCH	0.800
TUM(inv)	0.962

Table 5.2: Correlations between OECD Product Market Regulation Indicator (Network Industries), Fraser Institute Indicators of CCB and MCH, and Trade Union Membership

businesses and one that was not reduced over the sample period (Crafts, 2006; Frontier, 2012). Nevertheless, this regulatory indicator captures the general trend in UK policy which has been to lower some important regulatory barriers to entrepreneurship relative to their 1970 level.

The second part of the index for τ'_t reflects the tax environment faced by the would-be entrepreneur. This environment is highly complex at the microeconomic level, depending on the interrelationships between numerous individual tax (and subsidy) instruments, many of which were not in force throughout the full sample period. In the absence of a comprehensive measure of the 'effective' tax rate on the entrepreneur for the period 1970-2009, I use the top marginal income tax rate to proxy the extent to which the proceeds of an entrepreneurial endeavour are not appropriable by the individual entrepreneur. This approach is taken by others, e.g. Lee and Gordon (2005). The top marginal rate is measured as the tax rate incurred on an additional unit of income at the threshold of the top band, however the top band is defined in each period.[10] This is not to say that every entrepreneur gets into the top income tax bracket; many entrepreneurial ventures fail or make little profit, and the expected return to entrepreneurship is generally small. This top marginal tax rate is intended as a proxy for the profit-motive that is central to the notion of entrepreneurship, as we have defined it. Empirical work suggests that this is appropriate.[11]

There may be an argument for including the SME rate of corporation tax in the index, on the basis that reductions in this rate have lowered the costs of running a new business. An argument against assuming that lower corporation tax might enhance productive entrepreneurship is that, as mentioned above, reducing corporation tax relative to other forms of taxation (employee or self-employed labour income) distorts incentives to incorporate at the small end of the business

[10] Since the level of progressivity in the income tax schedule changes considerably over the sample period, the definition of the top band varies and that variation is not captured in our measure.

[11] Note the result in Baliamoune-Lutz and Garello (2014) that a reduction in marginal tax rates at the top of the income distribution relative to the marginal tax rate at average earnings increases entrepreneurship.

	CCB	MCH
Top Marginal Income Tax Rates	0.786	0.623
Corporate Tax (SME rate)	0.868	0.700

Table 5.3: Correlation Coefficients for Tax and Regulatory Components of Composite Index. Correlations are with the inverted, interpolated Fraser Index scores for CCB and MCH (i.e. higher score indicates higher regulation).

size distribution in way that has nothing to do with productivity growth. This seems to have happened in the UK when the SME corporation tax rate and starting rate on profits under £10,000 were repeatedly cut between 1997 and 2002 (Crawford and Freedman, 2010). For these reasons the corporation tax rate has not been included in the main τ'_t index. However, an alternative policy variable constructed from the labour market indicator and the corporation tax rate (in place of the top marginal income tax rate) has been used in robustness tests to check the best fit set of coefficients.

The top marginal income tax rate is measured annually. Between measurement points it is constant until policy changes it from one day to the next; it is a step function. Therefore the series is interpolated to a quarterly frequency on the assumption that missing quarterly values equal the annual values. Note that the series falls consistently over the sample period until 2009 with the introduction of the 50p tax rate on income over £150,000. Components of the indices $\tau(1)$ and $\tau(2)$ are plotted in Figure5-3. The top marginal income tax rate and the labour market regulation index are combined into a single measure by a simple average, with each series given equal weight (Figure 5-4).

The correlations between top marginal income tax rate, the corporation tax rate and the labour market regulation indicators are shown in Table 5.3. The high positive correlation between the series support the decision to combine the LMR indicator and the top marginal income tax rate in a simple average. This equally weighted combination is the main index proxying barriers to entrepreneurship in the empirical work below; it is referred to in the next section as $\tau(1)$, while $\tau(2)$ is an equally weighted average of LMR and the small companies' corporate tax rate. The main index $\tau(1)$ is plotted in Figure 5-4.

The index $\tau(1)$ falls over the sample period, though not in a regular way due to the steps in the marginal income tax rate. On visual inspection, the series could be a random walk with drift or a trend stationary process (perhaps with a structural break around 2002). A KPSS

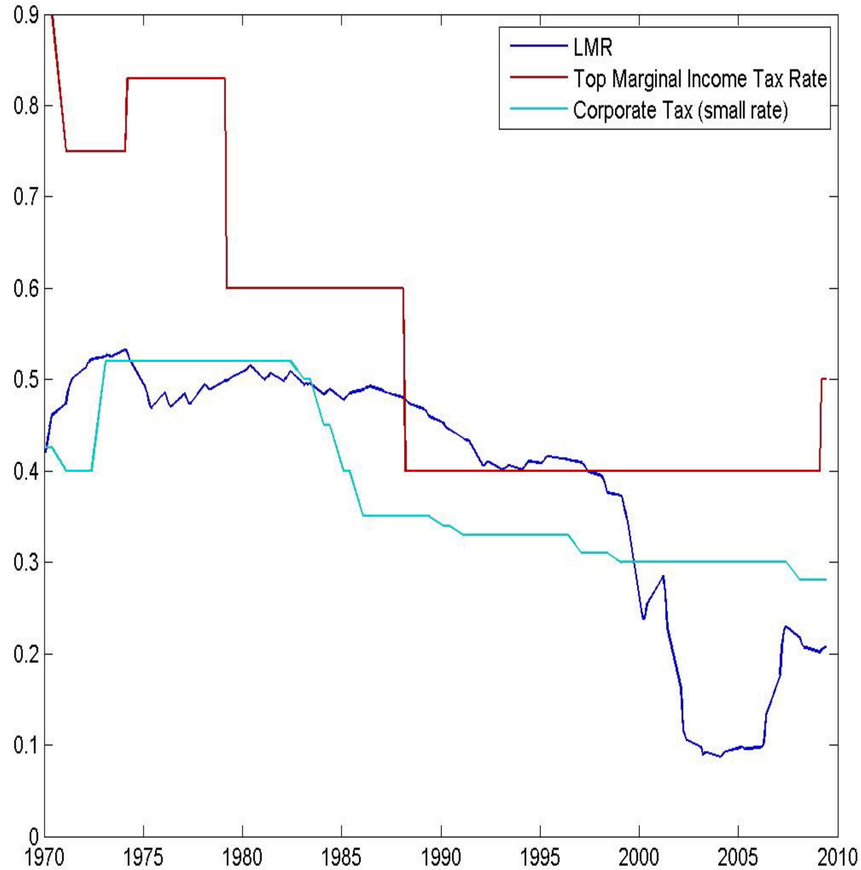

Figure 5-3: Top Marginal Income Tax Rate, Labour Market Regulation Indicator, and Corporation Tax (SME rate)

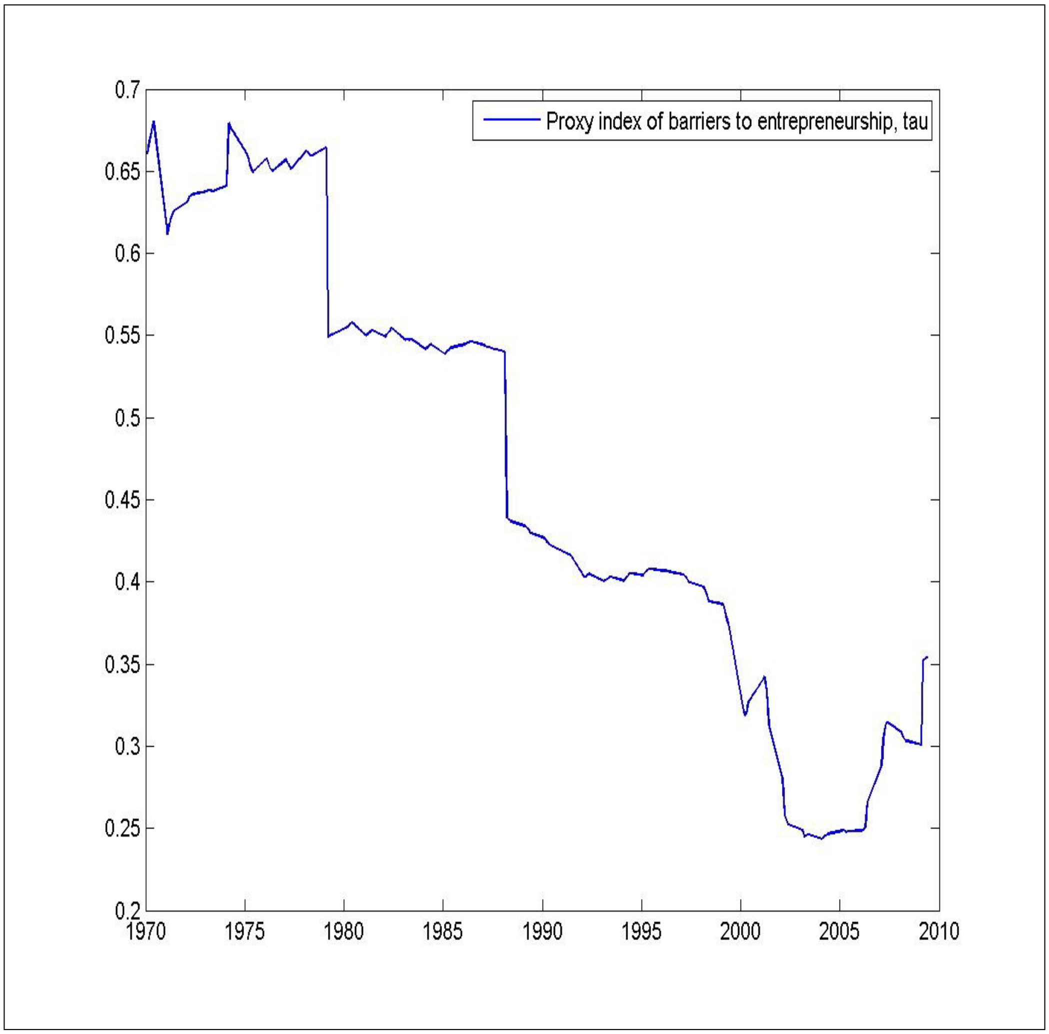

Figure 5-4: Evenly weighted combination of top marginal income tax rates and the labour market regulation indicator, $\tau(1)$

test for the trend and intercept specification does not reject the null of stationarity, even at the 10% significance level, though an ADF test with trend and intercept does not reject the null of a unit root. Given the ambiguity and the low power of these tests, it is reasonable to treat the series as trend stationary.[12]

Before solving the model, a linear trend term is estimated and removed and the detrended τ'_t rate is modelled exogenously as a stationary stochastic series with high persistence (see Chapter 2). The detrended $\tau(1)$ series is plotted against the changes in the Solow residual (in natural logs) for the original sample data in Figure 5-5. As this shows, there are some significant movements around trend in the policy variable and the interest is in whether such movements cause the behaviour of productivity. This is judged not through a reduced form regression on the historical data sample alone but through the Indirect Inference procedure described in Chapter 3; i.e. by seeing if, when the model is simulated many times for random sets of identified policy shocks, the average model-generated behaviour is close to the original sample data behaviour, when both are approximately described by a VARX(1).

5.2 Empirical work

The entrepreneur-driven model is tested for the starting calibration given in Chapter 2, and results presented in Section 5.2.1 below. The model is then re-estimated using the indirect inference estimation procedure, with results presented in Section 5.2.2. The calibration discussed in Chapter 2 is repeated in Tables 5.6 and 5.7 below; Table 5.6 shows parameters held constant throughout the analysis, while Table 5.7 shows parameters that are re-estimated in Section 5.2.2.

Results are presented for three different measures of τ' (see Table 5.4). The focus is on results for $\tau(1)$, while the other series are used in robustness tests.

5.2.1 Indirect Inference Test Results (Baseline Calibration)

Table 5.5 provides a key to parameter symbols. Parameters followed by # are estimated by Indirect Inference in the next section. Table 5.6 summarises the parameters that are fixed

[12] Note that if τ'_t was I(1) then according to the model relationships productivity would be I(2), which the data does not seem to support.

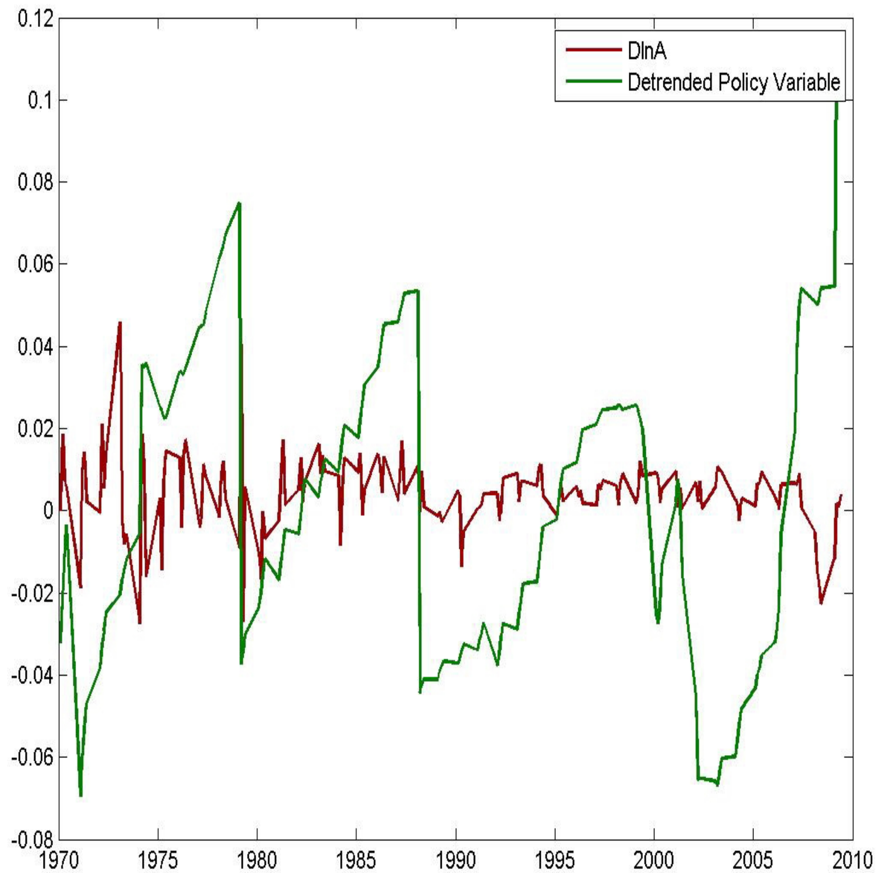

Figure 5-5: Linearly Detrended Policy Variable $\tau(1)$ and $D\ln A$

$\boldsymbol{\tau(1)}$	Equally weighted average: LMR and top marginal tax rate on personal income
$\boldsymbol{\tau(2)}$	Equally weighted average: LMR and small company tax rate on corporate profits
$\boldsymbol{\tau(3)}$	LMR alone

Table 5.4: Key to Policy Variables Used in Chapter 5

throughout the analysis, and Table 5.7 gives the starting calibration.

There is some freedom around the parameters b_1 and c_1 here, as discussed for the subsidy-driven model in Chapter 2. First of all, a wide variety of estimates have been found in the literature for the impact of tax and/or regulatory measures on entrepreneurial activities (c_1), for the impact of entrepreneurial activities on TFP growth (a_1), and for the 'direct' impact of policy determinants on TFP growth (b_1). As discussed in Chapter 4, the range of estimates for these has been found for different regression models and estimators, for different samples (in terms of both cross-section and time) and for different proxy measures of entrepreneurship (self-employment rates, new business rates or Global Entrepreneurship Monitor survey survey-based measures) or of the policy environment (marginal or average tax rates, tax progressivity, aggregate measures of 'regulation' versus disaggregate measures, subjective self-assessment by business versus objective measures based on official legislation - the latter may seem preferable but misses out dimensions of regulation as it is experienced by businesses, such as the burden imposed by enforcement). It was also argued in the preceding chapter that these empirical estimates are fragile, rarely being robust to changes in the model specification or to the removal of sample outliers and, most importantly, the regressions often suffer from endogeneity. Taking a value from the literature and applying it to this particular model would therefore be as arbitrary as picking a value for b_1 at random, particularly since there is limited specificity here about what variable z_t actually is in the data. With this justification, we take a starting value for b_1 at -0.11 and proceed to search around this value. A variance decomposition is then conducted using the model, in which the shocks to τ' and the shocks to the AR(1) productivity error term are bootstrapped independently, to see how much of the variation in the simulated $D \ln A$ series is accounted for by τ', and how much by the independent productivity shock e_A. This variance decomposition is an important diagnostic, as it will show whether the value of b_1 is sufficiently large for the policy variable to play a role in determining productivity growth, or whether it is effectively negligible in that process. In the latter case the exercise reverts to a test of an exogenous growth model, which is not interesting in this study of growth policy. To emphasize, the primary objective here is not to find the magnitude of the effect of policy on growth in the UK sample, but to see whether a set of parameters can be found for an identified UK DSGE model in which policy plays a significant role, such that that model is not rejected.

Parameter	Role
α	Labour share in output
β	Quarterly discount factor
δ	Quarterly depreciation rate (capital)
$\rho_1, \#$	CRRA coefficient on consumption
$\rho_2, \#$	CRRA coefficient on leisure
$\theta_0, \#$	Preference weight on consumption in utility function
$\omega, \#$	Home bias in consumption
$\omega_F, \#$	Foreign equivalent of ω
$\sigma, \#$	Import demand elasticity
$\sigma_F, \#$	Elasticity of substitution, domestic and imported consumption good
$\zeta_1, \#$	Impact of lagged capital stock on current capital demand (natural logs)
$\zeta_2, \#$	Impact of expected capital on current capital
$\zeta_3, \#$	Impact of output on current capital
$\zeta_4, \#$	Impact of the current real interest rate on current capital
$c_1, \#$	$\partial z_t / \partial \tau'_t$
$b_1, \#$	$\partial [d \ln A_t] / / \partial \tau'_t$
$g,$	Long run quarterly growth rate of output and capital

Table 5.5: Parameter Key

$\boldsymbol{\alpha}$	0.7	$\frac{EX}{C}$	0.361
$\boldsymbol{\beta}$	0.97	$\frac{G}{C}$	0.442
$\boldsymbol{\delta}$	0.0125	$\frac{EX}{Y}$	0.208
$\frac{K}{C}$	0.196	$\frac{IM}{Y}$	0.213
$\frac{Y}{C}$	1.732	$\frac{Y}{K}$	0.333
$\frac{IM}{C}$	0.369	g	0.004

Table 5.6: Parameters and Long-Run Ratios Held Fixed Throughout Investigation

$\boldsymbol{\rho}_1$	1.0	$\boldsymbol{\sigma}_F$	0.7
$\boldsymbol{\theta}_0$	0.5	$\boldsymbol{\zeta}_1$	0.51
$\mathbf{c}_1$	-0.06	$\boldsymbol{\zeta}_2$	0.47
$\boldsymbol{\rho}_2$	1.2	$\boldsymbol{\zeta}_3$	0.02
$\boldsymbol{\omega}$	0.7	$\boldsymbol{\zeta}_4$	0.25
$\boldsymbol{\sigma}$	1.0	$\boldsymbol{\omega}_F$	0.7
$\mathbf{b}_1$		-0.11	

Table 5.7: Starting Calibration, Other Parameters

$\mathbf{e}_r$	0.871	$\mathbf{e}_M$	0.967
$\mathbf{e}_A$	0.215	$\mathbf{e}_\tau$	0.938
$\mathbf{e}_N$	0.898	$\mathbf{e}_{CF}$	0.967
$\mathbf{e}_K$	0.940	$\mathbf{e}_{rF}$	0.935
$\mathbf{e}_{wh}$	0.957	$\mathbf{e}_G$	0.959
$\mathbf{e}_X$		0.941	

Table 5.8: AR(1) Coefficients of Structural Shocks to Variables Indicated by Subscript, Given Starting Calibration. Tau, C(F), r(F) and G are Modelled as Exogenous Stationary AR(1) processes

Variance in:	$D(A)$
Total variance in $D(A)$	0.00012
Due to e_A	0.00010
Proportion of total generated by e_A	84%
Due to τ'	0.00002
Proportion of total generated by τ'	16%

Table 5.9: Variance Decomposition, Starting Calibration; Tau(1) Model

The starting calibration implies the AR(1) coefficients for the structural shock processes in the model listed in Table 5.8. Evidently these shocks, though stationary once detrended, are still for the most part highly persistent. With this calibration, the Directed Wald test implies a strong rejection of the model at the 5% significance level for the VARX(1) auxiliary model described in Chapter 3, with endogenous variables Y_t and A_t and exogenous variables τ'_{t-1} and b^f_{t-1}. The normalised Mahalanobis Distance measure implies a test statistic of 2.465, or a Wald percentile of 100.

A variance decomposition for the log difference of productivity generated by this model shows that 16% of its total variance is due to the shock to tau, with the other 84% generated by the independent productivity shock (Table 5.9). Hence this model is comfortably distinct from an exogenous growth model.

5.2.2 Indirect Inference Estimation Results

The best fit set of coefficients discovered for this model with $\tau(1)$ as the policy variable driving productivity is given in Table 5.10. The search was limited to 30% either side of the starting set of coefficients. The test statistic implies a Wald percentile of 72, so this model is not rejected

$\boldsymbol{\rho}_1$	$\boldsymbol{\theta}_0$	$\boldsymbol{c}_1$	$\boldsymbol{\rho}_2$	$\boldsymbol{\omega}$	$\boldsymbol{\sigma}$	$\boldsymbol{\sigma}_F$
0.9712	0.5267	−0.0568	1.5198	0.5431	0.7676	0.8819
$\boldsymbol{\omega}_F$	$\boldsymbol{\zeta}_1$	$\boldsymbol{\zeta}_2$	$\boldsymbol{\zeta}_3$	$\boldsymbol{\zeta}_4$	$\boldsymbol{b}_1$	***Wald%***
0.8819	0.6359	0.3349	0.0240	0.2365	−0.1209	72.23

Table 5.10: Wald Minimising Coefficient Values for Tau(1) Model

at the 5% significance level; indeed, the Wald statistic is well within the non-rejection area of the bootstrap distribution. Impulse response functions for this calibration have been checked and are logically sound for each shock, not deviating qualitatively from the baseline calibration IRFs. The implied AR(1) coefficients for the exogenous stochastic processes are reported in Table 5.11.

Many of these coefficients have moved some way from their starting values. Exceptions are the CRRA coefficient in the utility function for consumption, which has decreased by less than 3%; also the preference weight on consumption, θ_0, has increased by only 5%, as has c_1. The coefficient of relative risk aversion for leisure (ρ_2), is 27% higher than its starting value of 1.2; the domestic preference for domestic goods (ω) has decreased by 22%; and the elasticity of imports has decreased by 23%, while the elasticity of exports ($\frac{\sigma_F}{\omega}$) has increased to 1.62. One important constraint on the model is the Marshall-Lerner condition, stating that the sum of the elasticities of imports and exports with respect to a change in their relative price (the variable Q here) must be greater than or equal to one. According to these estimates, the elasticities sum to 2.391 and the condition is satisfied. The long run constraint on the capital equation that $\zeta_3 = 1 - \zeta_1 - \zeta_2$ is also approximately satisfied. The estimates of the capital equation coefficients imply that the past value of capital exerts a strong pull (0.636) on the current value, indicating high adjustment costs. The lower estimate of the coefficient on the forward expectation of capital, ζ_2, at 0.3349 implies a fairly large discount rate for the firm, far higher than that of the consumer. This captures the effects of idiosyncratic risks faced by the price-taking firm, e.g. the risk that the general price level will move once his own price is set in his industry. I assume that idiosyncratic risks to the firm's profits cannot be insured and that managers are incentivised by these. We can also think of there being a (constant) equity premium on shares ˜though this, being constant, does not enter the simulation model.

Given these parameter values, a variance decomposition is calculated for $D \ln A$ (for which

$\mathbf{e}_r$	0.873	$\mathbf{e}_M$	0.951
$\mathbf{e}_A$	0.237	$\mathbf{e}_\tau$	0.968
$\mathbf{e}_N$	0.898	$\mathbf{e}_{CF}$	0.918
$\mathbf{e}_K$	0.990	$\mathbf{e}_{rF}$	0.967
$\mathbf{e}_{wh}$	0.959	$\mathbf{e}_G$	0.935
$\mathbf{e}_X$		0.959	

Table 5.11: AR(1) Coefficients of Structural Shocks to Variables Indicated by Subscript, Given Estimated Coefficients

only the τ' innovation and the independent productivity innovation are relevant), and also for the other endogenous variables. In the system there are eleven (mostly highly persistent) stationary shocks, some of which affect net foreign assets (a unit root endogenous variable), and two of which enter the non-stationary productivity process. Therefore some non-stationarity is introduced into the system even by the stationary shocks, and the non-stationarity induced by the shocks to tau and to productivity also engender significant non-stationarity in the simulations, but we can be confident that variances taken over the finite sample period of 30 years are bounded. Over the simulation period we can calculate the variation induced in the endogenous variables by each of these shocks separately, and see which are relatively more important in creating volatility in the model. This should give us some insight into the historical data from 1970-2009 given the non-rejection of the model, though note that the model has so far only been tested on the behaviour of output and productivity, given the policy variable and net foreign assets. It would certainly be rejected on the joint behaviour of all the endogenous variables (as we know from work using the indirect inference test on fuller auxiliary models, for which the power of the test rises very quickly). The variance decomposition is obtained by bootstrapping the model and calculating the variance in each simulated endogenous variable for each shock separately, and reported in Table 5.12.

	$\mathbf{r}$	$\mathbf{Y}$	$\mathbf{N}$	$\mathbf{K}$	$\mathbf{C}$	$\mathbf{w}$	$\widetilde{\mathbf{w}}$	$\mathbf{X}$	$\mathbf{M}$	$\mathbf{Q}$	$\mathbf{b}^F$	$\mathbf{A}$	$\mathbf{d(A)}$
$\mathbf{e(r)}$	0.1833	0.0016	0.0080	0.0033	0.0370	0.0471	0.0005	0.0118	0.0800	0.0114	0.0396		
$\mathbf{e(A)}$	0.0453	0.1320	0.1056	0.0244	0.1018	0.0611	0.1339	0.1342	0.0880	0.1298	0.0087	0.1583	0.8146
$\mathbf{e(N)}$	0.0150	0.0012	0.0111	0.0002	0.0012	0.0251	0.0086	0.0005	0.00001	0.0005	0.0008		
$\mathbf{e(K)}$	0.1748	0.1515	0.1308	0.8323	0.1067	0.0568	0.1316	0.1091	0.0574	0.1055	0.0208		
$\mathbf{e}(\widetilde{\mathbf{w}})$	0.1314	0.0070	0.0786	0.00003	0.0106	0.0054	0.0006	0.0023	0.000004	0.0052	0.0004		
$\mathbf{e(X)}$	0.0174	0.0044	0.0511	0.00002	0.0704	0.2564	0.0004	0.0452	0.2395	0.0653	0.5242		
$\mathbf{e(M)}$	0.0034	0.0016	0.0180	0.00002	0.0588	0.1743	0.0001	0.0434	0.1364	0.0419	0.1642		
$\boldsymbol{\tau}'$	0.2876	0.6997	0.5865	0.1370	0.5193	0.1709	0.7238	0.6174	0.1559	0.5970	0.1008	0.8417	0.1854
$\mathbf{C}_F$	0.0014	0.0006	0.0070	0.00001	0.0336	0.0836	0.0001	0.0114	0.0945	0.0195	0.0560		
$\mathbf{r}_F$	0.1377	0.0003	0.0027	0.0027	0.0616	0.1192	0.0005	0.0247	0.1483	0.0239	0.0843		
$\mathbf{G}$	0.0027	0.00004	0.0006	0.00001	0.0001	0.0001	0.00001	0.0001	0.00001	0.00005	0.0002		

Table 5.12: Variance Decomposition for Tau(1) Model Given Estimated Coefficients

Auxiliary model	**(1)**	**(2)**	**(3)**	**(4)**
Endogenous	Y, A	Y, A, r	Y, A, Q	Y, A, K
Exog (included in test)	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}
Exog (excluded from test)	*trend*, *const*	*trend*, *const*	*trend*, *const*	*trend*, *const*
Wald percentile	72.226	82.3718	90.1622	92.9304
Auxiliary model	**(5)**	**(6)**	**(7)**	**(8)**
Endogenous	Y, A, N	Y, A, C	Y, A, r, Q	Y, A, N, C
Exog (included)	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}
Exog (excluded from test)	*trend*, *const*	*trend*, *const*	*trend*, *const*	*trend*, *const*
Wald percentile	94.4128	95.0495	89.4747	94.0382
Auxiliary model	**(9)**	**(10)**	**(11)**	**(12)**
Endogenous	Y, A, r, K	Y, A, r, N	Y, A, Q, N	Y, A, K, C
Exog (included)	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}
Exog (excluded from test)	*trend*, *const*	*trend*, *const*	*trend*, *const*	*trend*, *const*
Wald percentile	94.8023	94.9153	95.1192	94.2632

Table 5.13: Indirect Inference Wald Test Results, Alternative Auxiliary Vector Error Correction Models

The variance decomposition illustrates that the policy variable plays a significant part in generating variation in the level of output and consumption, as well as labour supply (and hence the unit cost of labour to the producer) and the real exchange rate. It is also responsible for generating over 10% of the variation in the quarterly growth rate of productivity. Therefore we can be sure this is distinct from an exogenous growth model; policy has an important effect on the economy in this model.

The model with this set of coefficients was also tested using some alternative auxiliary models, in which more endogenous variables are included. This should provide a more stringent test of its macroeconomic performance. Results are reported in Table 5.13.

For the second model, adding the real interest rate as an endogenous variable actually improves the Wald relative to the two endogenous variable case. The model can also comfortably withstand the addition of the real exchange rate and capital to the auxiliary VECM without the test statistic falling in the rejection region at the 5% significance level. The addition of labour as an endogenous variable worsens the model's performance against the data; though the test statistic is still within the non-rejection region, it is close to the border. This may be due to measurement error in the labour supply variable, which includes some activity that we would prefer to class as 'entrepreneurship', or perhaps some misspecification around c_1 in the labour supply equation. Likewise the model is borderline rejected at 5% significance when consumption is added as an endogenous variable. Consumption is badly measured in aggregate data, due to the presence of durable goods which rightly belong in physical capital investment data.

The model can accommodate r and Q in addition to Y and A in auxiliary model (7), passing the test comfortably at 5% significance. The real exchange rate is the key relative price variable in an open economy model and capturing its behaviour adequately is a strong point in this model's favour. The fact that it is captured jointly with the real interest rate is also encouraging, as the real uncovered interest parity identity relates these variables tightly. Auxiliary model (8) is interesting from a welfare point of view, since both consumption and labour supply enter the utility function. These variables together with Y and A are captured well jointly by the model; in fact the joint performance of N and C implies a non-rejection at the 5% level, and a lower Wald percentile than when either C or N is tested without the other. This illustrates the important statistical difference between joint moment-matching and single moment-matching.

In summary, the UK model performs well for the endogenous variables that are key for policymakers: output and productivity on the real side, real interest rates and real exchange rates on the relative price side, and consumption and labour supply for welfare purposes.

5.2.3 Robustness

Both the baseline calibration and the Wald-minimising set of coefficients discovered for the $\tau(1)$ series were also tested on the baseline auxiliary model (VECM 1) using $\tau(2)$, the equally weighted simple average of the LMR indicator with the tax rate on corporate profits (small business rate). For the baseline calibration in Table 5.7, the normalised Mahalanobis Distance statistic is very similar to that obtained for $\tau(1)$, at 2.33. This implies a Wald percentile of 100, i.e. a rejection of the model. When the Wald-minimising calibration in Table 5.10 is used with the $\tau(2)$ series, the normalised Mahalanobis Distance statistic is 1.0230. This is larger than the statistic obtained for $\tau(1)$, corresponding to a Wald percentile of roughly 85, but it is still well inside the non-rejection region at 5% significance.

The same tests were carried out for $\tau(3)$, the labour market regulation indicator alone. For the baseline calibration the model is again strongly rejected, with a normalised Mahalanobic Distance statistic of 3.429. For the Wald-minimising coefficient set in Table 5.10 the model driven by $\tau(3)$ is also not rejected at the 5% significance level, yielding a normalised Mahalanobis Distance statistic of 1.568 corresponding to a Wald percentile of 94.41.

These robustness checks show that the non-rejection of the model for these coefficients is not sensitive to the composition of the policy index. The model passes the test for a policy driver reflecting labour market flexibility alone, as well as when tax indicators are added to the picture. We note that the inclusion of the top marginal income tax rate, with its large step changes, yields a lower Wald percentile for the model.

Robustness was also carried out around the interpolation technique of $\tau(1)$. The results do not change when the Denton method is applied in levels rather than differences for the labour market indicators. Where components have been interpolated to a quarterly frequency, robustness checks around the interpolation technique show the conclusions are unaffected.[13]

5.3 Summary

In this chapter, the model in Chapter 2 has been set up on the assumption that temporary movements in tax and regulatory policy around its long run trend drive short-run productivity growth via marginal incentive effects on innovative 'entrepreneurial' activity. The model has been tested at the level of its simulated macroeconomic behaviour for its appropriateness to the UK experience between 1970 and 2009. The tax and regulatory policy environment for this period is proxied by an equally weighted combination of the top marginal rate of personal income tax and a labour market regulation indicator; the latter is in turn a combination of a survey-based centralised collective bargaining indicator and an index of the marginal cost of hiring calculated by the World Bank. The work done in this chapter shows that these proxies for 'barriers to entrepreneurship' do have an effect on growth.

The model has been estimated using the Indirect Inference procedure and the Directed Wald-minimising set of coefficients implies a comfortable non-rejection of the model for this UK sample at the 5% significance level. The non-rejection is robust to adjustments around the

[13] I checked constant match interpolation against quadratic interpolation.

policy variable; it holds when the small companies rate of corporate tax is used in place of the top marginal income tax rate, and when tax rates are excluded altogether. Moreover, the model performs well when a variety of endogenous variables are added to the auxiliary VARX(1), explaining the real interest rate and real exchange rate behaviour, as well as physical capital, labour supply and consumption in various combinations. A variance decomposition for the estimated model shows that the policy variable is responsible for much of the simulated variance in the endogenous variables, due to its permanent effects on non-stationary productivity. The estimated marginal impact of the policy variable on the change in productivity is -0.12, implying that a 1% reduction in this entrepreneurship penalty rate increases productivity growth in the short run by 0.12 percent per quarter. This is not a statement about long-run growth rates, which are outside the scope of this study.

Interpreting the policy variable as a proxy of 'barriers to entrepreneurship' implies that it targets a specific entrepreneurial growth channel, but here this channel has not been formally distinguished from R&D or indeed any other channel; the interpretation relies instead on existing empirical work suggesting direct policy-entrepreneurship links (this work is discussed in Chapter 4). The precise innovation activities through which the policy $\tau(1)$ translates into productivity effects are left open. The next part of this thesis is concerned with policy drivers that more obviously isolate the R&D channel, affecting the marginal cost of formal R&D investment. If such a policy is rejected as a productivity driver, then the growth effects of our tax and regulatory policy variable can be more confidently attributed to an entrepreneurial channel; a channel more closely related to business start-up activity than to formal expenditure on R&D. However, a non-rejection of R&D policy-driven productivity growth will blur the interpretation of the channel through which $\tau(1)$ operates, making a more general 'barriers to business' label more appropriate than 'barriers to entrepreneurship', or else requiring a very broad understanding of entrepreneurship.

Chapter 6

Policy-Driven Growth via Business R&D: Motivation and Literature Review

6.1 Introduction

Since Schultz (1953) and Griliches (1958) there has been a thriving and influential theoretical and empirical literature linking R&D activity to economic growth, and the R&D growth channel is now taken as given by many.[1] For instance, Warda (2005) states simply that "Innovation is the engine of growth in a knowledge economy, and Research and Development (R&D) is the key ingredient of the innovation process", going on to say that "Government has a major supporting role in this area by providing a favourable business environment, including appropriate and competitive incentive programs for R&D." (p.2)

[1] OECD R&D definition: "Research and experimental development (R&D comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications." (Frascati Manual, 6th Ed., 2002; paragraph 63). The definition covers basic research, applied research, and experimental development. Basic research is ... conducted "without any particular application or use in view", whereas applied research is "directed towards a specific practical aim or objective." Experimental development is "systematic work... directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed."(section 64). OECD figures between 2002 and 2012 show that R&D performed by the UK private sector generally consists of applied research or experimental development which are more 'near market' activities than basic research.

In this chapter I propose a model in which that endogenous growth hypothesis is embedded. The question of interest is whether government policy intervention has incentivised the private sector in the pursuit of profit-motivated R&D activity, and so enhanced innovation and productivity growth in the UK over the sample period. The model is tested and estimated using Indirect Inference methodology.

Why is the question still worth testing? In spite of the body of literature addressing it, there is still reason to investigate the ability of R&D-specific policies to generate significant extra innovative activity and productivity growth (and so welfare). R&D expenditures and new patent numbers are convenient measurables and often used as proxies for innovation outputs in empirical studies, but we might question the extent to which they capture innovation. Formal business R&D is certainly not the only source of innovation, which also occurs through informal learning by doing, non-R&D expenditures on knowledge-enhancing activities and the commercialisation of new ideas via start-up. Moreover, these proxies may be more closely correlated with non-innovative activities; firms may patent as a signal to capital markets, or to earn through licensing revenues, for instance. Subsidies directed towards formal private sector R&D may then not be the most efficient use of the public finances when the real objective is productivity growth, rather than patents or R&D expenditure for their own sake.

Analysis of trends in R&D intensity and changes in productivity growth across OECD countries does not indicate a clear, strong association between them. Indeed, in several countries increasing stocks of business R&D and patent numbers are associated with declining productivity growth (Braunerhjelm et al. (2010); Westmore, 2013). Of course, if these are poor proxies for true innovative capital then this is not informative of the general validity of policies targeting the innovation process; and such eye-balling of general trends does not amount to much. A rigorous investigation must control adequately for the counterfactual.

Finally, most OECD governments feel considerable budgetary pressure in 2014, the UK being no exception, and this is leading the drive for efficiency improvements in public spending of scarce resources. Ex post evaluation of past government policies is desirable to gauge public spending effectiveness and efficiency, and R&D policy programmes represent a considerable outlay of public money. The continued subsidisation of business R&D must be formally justified, like every other area of spending.

To motivate the R&D-driven growth model tested in Chapter 7, this chapter provides a review of some existing literature on this question, as well as some background on UK R&D and policies designed to target it. Rather than focusing on policies targeted at a more micro level, i.e. at particular sectors, industries or types of firm, which lend themselves more to event studies or micro-evaluation approaches, I look at aggregated policy variables and their impacts at the macroeconomic level.

6.2 Literature Review

6.2.1 R&D Spillovers: Theory and Evidence

There is a sizeable microeconometric literature estimating the rates of return on R&D investment at the private level and at the social level. For surveys see e.g. Griliches (1998, Chapters 5 and 11), Hall et al. (2010), and Becker (2013). Though the results fall into a reasonably large range, the consensus is that both returns are positive and significant, and that social returns are higher by a factor of two to four (Griffith, 2000, p.9), signifying large spillovers from private innovation to the aggregate.

Such spillovers overcome diminishing returns to accumulable factors in the aggregate production function, generating sustained economic growth; but they also undermine private incentives to innovate since the innovator cannot appropriate the full return from his investment (e.g. Aghion and Howitt, 1992; Romer, 1990). The theoretical endogenous growth literature on spillovers was discussed in some depth in Chapter 4, so a brief recap of the policy implications will suffice here. The equilibrium innovation rate in such models generally depends on the interaction of various effects, some of which work in different directions: appropriability and spillover effects drive a wedge between the private and social returns to research, undermining the incentives of the researcher and suppressing the market rate of innovation below the social optimum, while the business stealing effect (the incentive for a competitor firm to enter and acquire the market, destroying the rents of the incumbent monopolist) can push innovation above the socially optimal rate, also a welfare-inferior outcome. Arrow's replacement effect (Arrow, 1962) implies that the incumbent monopolist has low incentives to innovate further, so that technological progress rests with competitors; a model featuring this effect may lead to a low innovation equilibrium when barriers to entry are high.

The broad flavour of the policy recommendations coming from such models, supposing the downward incentive effect to dominate, is that research activities should be subsidised directly (or indirectly through fiscal incentives) in order to bring private returns into line with the social rate, and that protection of intellectual property rights should be increased, enabling the innovator to appropriate a larger portion of the returns to his investment in spite of the non-rival nature of knowledge outputs. The underlying structure of the environment can also play a role, depending on the particular model; competition policy and the reduction of barriers to entry and other market frictions may increase the innovation rate, though this is theoretically ambiguous (as discussed in Chapter 4). Policymakers may also be able to increase the innovation through the R&D channel by subsidising human capital accumulation, exploiting complementarities between the two activities that arise through the use of highly skilled workers as an input to the R&D process (e.g. Varga and 't Veld, 2011). However, this is not the focus in the current paper.

Other spillover channels have been posited in the R&D literature. Grossman and Helpman (1991a) look at international spillovers in two models. If these pass perfectly across borders there is no role for domestic subsidies to R&D in aiding catch-up to the technology frontier (Chapter 7); but if spillovers are geographically bounded (as in the model in Chapter 8) then initial cross-country differentials in innovation stocks will lead to a widening of productivity gaps over time. In that case countries with lower initial levels should subsidise R&D in order to facilitate catch-up. Microeconometric studies finding that technology spills over faster within countries than across borders include Branstetter (1996) and Eaton and Kortum (1994). Griffith et al. (2003, 2004) note the role of R&D in enhancing the capacity for the domestic economy to absorb international spillovers and find evidence for this channel as a productivity determinant at the industrial level in a panel of OECD countries, so reinforcing the argument for domestic subsidies to R&D.

On the other hand, the idea that absorptive capacity enables spillovers (particularly spillovers within industries or countries) may somewhat undermine the rationale for subsidies. If spillovers from private investment to other firms or industries are costless (and there are no counteracting effects), then subsidies seem the obvious policy choice to raise investment incentives to the point where marginal private and social benefits are equal, generating the socially optimal level of innovation. If, however, knowledge does not diffuse costlessly, but requires firms to do their own R&D in order to absorb spillovers from the R&D of others, this adds an upward 'absorption' incentive to R&D into the mix, since returns to own R&D are increasing with the overall spillover pool (see e.g. Cohen and Levinthal, 1989; Geroski 1993, 1995). These complementarities between own and others' R&D may mean that the market equilibrium level of investment in R&D is not seriously below the social optimum (or at least, the extent is again unclear), leaving less of a role for subsidies. Such complementarities feature in industries where there are simultaneously high spillovers and high R&D investment, like aircraft, semi-conductors, computers, electronic components and communications equipment (Spence, 1984; Levin, 1988), and these industries tend to be a focal point for innovation policies. If incentives to invest in R&D are not undermined by spillovers, but on the contrary are pushed up by rivalry and strategic interaction, then additional policy intervention may even push R&D investment beyond the social optimum (Klette et al., 2000).

Equally, the presence of feedback between own and external R&D introduces the possibility of multiple equilibria for R&D at the industry or even economy level (Matsuyama, 1995). If there is low R&D to begin with, a low innovation equilibrium results, but if R&D can be stimulated by government intervention in the early stages of a new industry (where government subsidies are often targeted) then a virtuous cycle of spillover complementarities can lead to a high innovation equilibrium. This kind of thinking motivates 'infant industry' policies. Klette and Moen (1999) show the failure of this type of policy intervention for IT-related manufacturing R&D in Norway, which they put down to informational frictions. They conclude that although a simple game theoretic construct might make policy intervention a clear choice, in practice, in a non-frontier economy when the technology frontier is progressing rapidly, "policymakers and bureaucrats often lack the information needed to improve on the market solution." (p. 73) Having said this, Klette et al. (2000) point out that a downward selection bias may be operating on their estimate of the subsidy programme impact (on which more below).

Other literature has looked at complementarities between different types of domestic R&D, such as spillovers from R&D conducted in higher education institutions to the private sector (e.g. Khan et al., 2010). It is not within the scope of the present chapter to discuss every potential spillover mechanism that may lead to enhanced aggregate productivity growth through the R&D channel. The reader is referred to the survey in Khan et al. (2010). This discussion should serve to emphasise that theoretically the interaction of some or all of these effects, as well as any other potential effects that have not had attention, might lead to excessive innovation or too little at the aggregate level, depending on their relative sizes. The question of whether the market economy generates a sub-optimal level of innovation in the absence of subsidies is an empirical one.

6.2.2 R&D Policy Trends

Before proceeding to the empirical literature on the policy determinants of R&D and growth, a brief overview of R&D policy trends in the UK and across the OECD is useful to set this literature in context. In summary, three significant policy shifts have emerged since the 1980s. The proportion of Business Enterprise R&D (BERD) financed by government fell sharply, then levelled off from the late 1990s; there has been a strong movement towards indirect government support for R&D in the form of tax credits; and there has been interest in increased patent protection, though for the UK this is less significant.

The early 1980s saw a strong downward trend in direct government funding for private sector R&D expenditure, as supply side policy gained popularity across the OECD and many industries were privatised. In 1981 the UK level was high and far above the OECD average; the percentage subsequently plunged across the area (see Figure 6.1). However there has been a notable levelling out since the late 1990s. This halting of the downward trend seems to have been a response to the R&D-focused innovation literature, at least in part.

Another increasingly important aspect of the R&D policy mix is the trend towards fiscal incentives, adopted by the majority of OECD countries over the last decade. Tax credits constitute indirect government financial support; they reduce the marginal cost of R&D investment for the firm and do not require government to screen the projects that firms choose to undertake. Figure 6.2 shows the OECD 'tax subsidy rate', constructed as one minus the B-Index (Warda, 2001). The B-Index measures the income required before tax in order to break even on one unit of R&D spending (in USD); it is lower when the tax credit is higher. Thus the subsidy rate proxies the generosity of the tax schedule towards business R&D. A number lower than

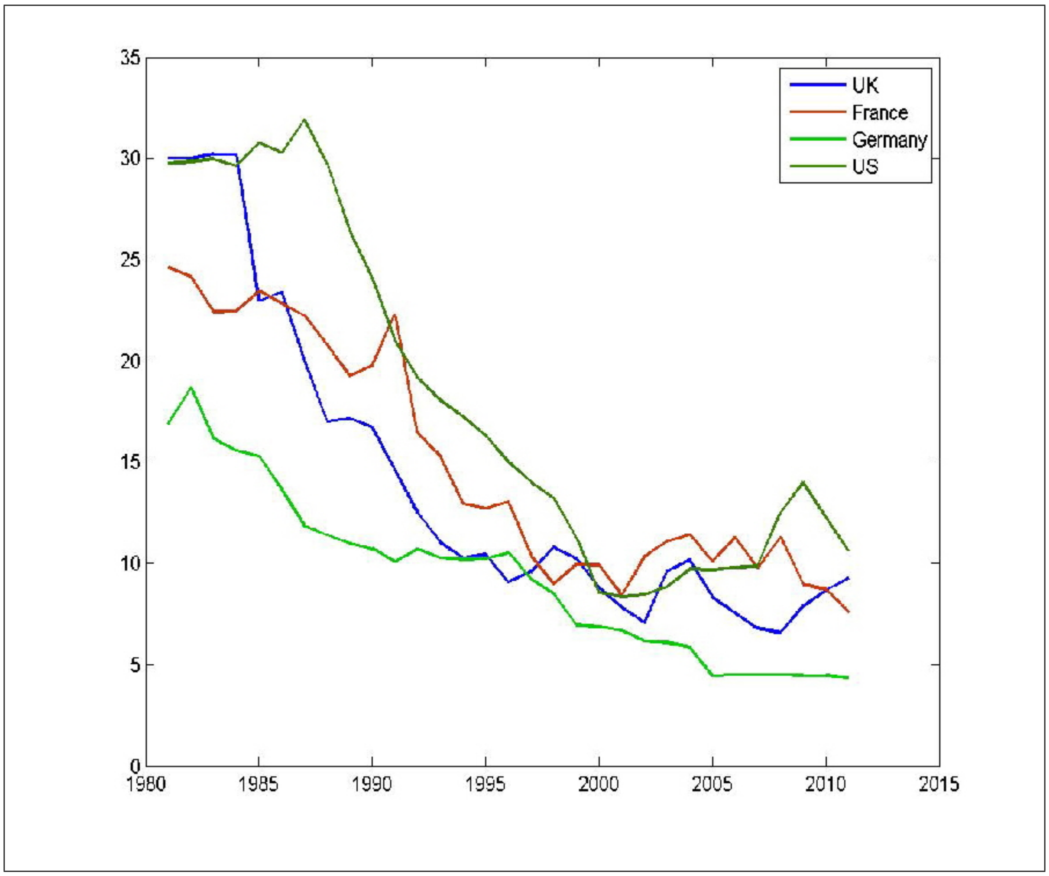

Figure 6-1: % BERD Financed by Government (Source, OECD)

zero for the subsidy rate indicates that the tax code penalises R&D, while a number greater than zero indicates tax preference towards R&D. For the UK this measure includes the large company R&D expenditure credit introduced in 2002, but it excludes the more generous SME R&D tax credit introduced in 2000, as well as accelerated depreciation schemes. The SME tax credit is also excluded from the aggregate measures of BERD funded directly by government, so this element of government policy is generally missing altogether from cross-country comparisons. Given the differences in design of tax credit schemes, which may be volume-based (as in the UK) or incremental (applying only to increases in expenditure above some threshold) and comprise various additional allowances, the comparability of the tax subsidy rate across countries may be limited. Note that the SME and the large company R&D tax credit became more generous in the UK as of 2013, when the complementary Patent Box scheme was also introduced, a credit on profits arising from patents (HM Treasury, 2010a). The patent box alone was predicted to cost £1.1bn per year in the June 2010 Budget (HM Treasury, 2010b, Table 2.4, footnote 3); these are expensive policies, at least in the short run.

The last major trend in OECD policy emerging from the innovation literature surveyed in this chapter is the general increase in patent protection; see Figure 6.3.. According to the Ginarte-Park Index (Park, 2008) the UK, Belgium and the US had the highest levels of patent protection amongst this group of OECD countries in 1985. Between 1985 and 2008 the UK level of patent protection increased, but many others increased by more and overtook; however, the difference in the level between the 2008 leader (the US) and the UK is very small. Given the lack of variation in this index over the time period, we would not expect the addition of this dimension to a composite R&D policy indicator to add much information.[2]

6.2.3 Evaluating R&D Policy Effectiveness

The trends discussed above reflect the traction gained in policy circles by spillover-based arguments for government support to R&D, both direct (subsidies) and indirect (tax incentives and broader 'framework' policies to modify the choice architecture of the R&D decision envi-

[2] Intellectual property rights protection is classified as a framework policy in the literature (e.g. Westmore, 2013), and other framework policies sometimes looked at in the context of R&D incentives include labour market and product market regulation. This is another opportunity to underline that in Chapter 5, the R&D growth channel is not necessarily excluded by our choice of policy variable $\tau(1)$.

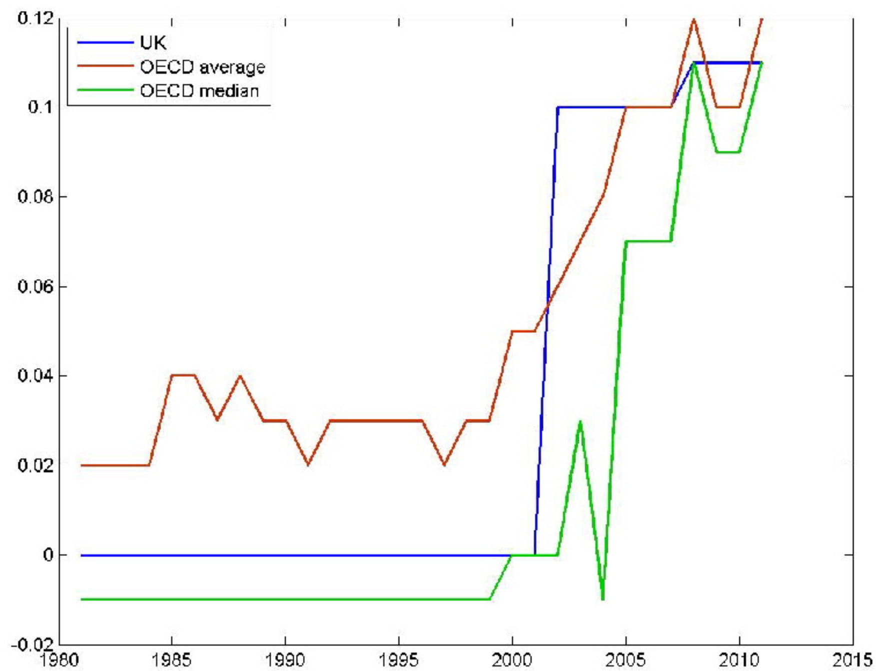

Figure 6-2: Indirect Subsidy Rates (1-B-Index), UK and OECD. Source, OECD.

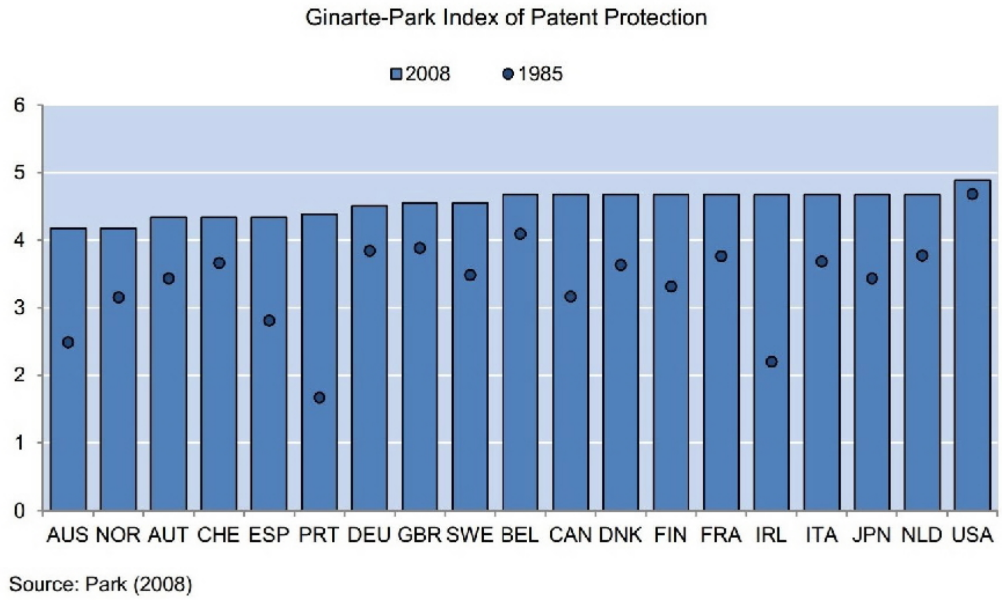

Figure 6-3: Ginarte-Park Index of Patent Protection. Figure Reproduced from Westmore (2013, p. 13, Figure 6).

ronment). The idea is that governments subsidise projects that have large expected returns to society but which would not be picked by private investors. Of course, there is a large empirical literature evaluating whether government programmes achieve what they set out to do. The risk is that, rather than encouraging additional private spending on R&D, subsidies go towards funding projects that the private sector would have funded anyway in their absence. David et al. (2000) survey 35 years of econometric analysis of this question, concluding that "The findings overall are ambivalent" (abstract). Klette et al. (2000) review some microeconometric studies evaluating the impacts of government subsidy programmes designed to stimulate private sector R&D in the manufacturing sector, and their paper raises several important issues with this literature that merit discussion. Of the papers discussed there, Irwin and Klenow (1996), Lerner (1998), Branstetter and Sakakibara (1998) and Griliches and Regev (1998) all find evidence that participation in the government subsidy programme is associated with significant benefits. Klette and Moen (1999), on the other hand, find that Norwegian government subsidies, though large, had no positive impact relative to those not subsidised; this result holds at the firm level and at the industry level, when supported industries are compared both to other Norwegian industries and separately to similar OECD industries.

However, Klette et al. (2000) note various selection biases in the samples. Selection bias implies problems with the 'control group' in the quasi-experiments. In Irwin and Klenow (1996), Lerner (1998) and Klette and Moen (1999), the proposed counterfactual is the group of non-supported firms. They use a difference-in-differences setup with a firm-specific fixed effect, which ought to capture any underlying firm heterogeneity correlated with programme participation, provided that those characteristics are constant throughout the sample. The process then contrasts the change in performance of the 'treated' group (those who received a subsidy) before and after treatment, with that of the untreated. The question is whether these non-supported firms capture what the treated firms' experience would have been in the absence of the treatment. Klette et al. (2000) point out that the firm-specific fixed effect does not control for selection bias when there are temporary shocks which correlate with the probability of selection for the subsidy programme. This is the so-called 'Ashenfelter-dip', where temporary bad performance affects the probability of being selected for a treatment; when programmes pick winners, good performance will increase the probability of selection. The point is that the direction of the bias depends on the particular circumstances and characteristics of the programme or sample being analysed.

Furthermore, the presence of spillovers from subsidised to unsubsidised firms, which is generally the rationale behind government intervention in the R&D process, would make the untreated firms a poor control group. If the effects of subsidised private R&D spill over to other similar firms then we would expect all firms of that type to show a similar (better) performance, regardless of whether they received the subsidy; and the result in this framework would not be observably different if the subsidy had no impact on performance for the treated group. Branstetter and Sakakibara (1998) note the potential for spillovers in their sample and investigate further. They find that consortium-membership raises the firm's propensity to patent, and when they include a spillover variable as a regressor the interaction of this variable with consortium-membership is positive and significant in a random effects model, signifying that consortium-membership enhances the impact of other firms' R&D on own-firm patenting. The spillover variable is constructed as a weighted sum of other firms' R&D, where weights are higher for more technologically similar firms. Therefore the weighting mechanism used to capture the increased likelihood of spillovers between firms based on their similarities is closely related to the matching procedure in Blundell and Dias (2000, Section 4.4), which matches 'treated' and 'untreated' firms with similar characteristics in order to estimate the additional effect of the treatment. The point is that matching firms between treated and untreated groups in order to satisfy usual matching criteria (which ought to signify an appropriate control; see Heckman et al. 1998) makes the presence of spillovers more likely, so invalidating the control group. Studies evaluating the impact of policies on business R&D at the firm and industry level must address these issues for their findings to be reliable.

More recent microeconometric studies evaluating the effectiveness of subsidy programmes include Einio (2014), Takalo et al. (2013), both of which look at Finland, and Overman and Einio (2012) for disadvantaged areas in England. These authors take identification of the causality from R&D subsidies to firm performance more seriously. Bronzini et al. (2010) use a regression discontinuity approach to look at the impact of R&D subsidies on Italian firms.

Criscuolo et al. (2012) conduct a UK specific micro-econometric study of the impact "Regional Selective Assistance" subsidy programme on firms, using a matching approach. Instrumental variables are constructed using exogenous changes in European state-aid regulations (cf. Einio, 2014). Their results indicate treatment effects of the subsidy programme on employment, investment and net entry rates, though these effects are only present for small firms (firms with fewer than 150 employees). They find no effect of subsidies on TFP.

Foreman-Peck (2013) uses propensity score matching to estimate the effectiveness of UK innovation policies in stimulating innovation and growth for SMEs in both manufacturing and service sectors between 2002 and 2004. Self-reported innovation from the Fourth Community Innovation Survey (DTI, 2006) is preferred as a measure of innovation output to R&D expenditure figures which "markedly under-report research activity and innovativeness" among SMEs (p.56). He finds significant, positive impacts of policy on supported firms' self-reported innovation outcomes and enterprise turnover growth relative to unsupported firms. Since omitted spillover impacts between the groups would imply a downward bias on these estimates, they are interpreted as a lower bound to the gains from policy; though if there is selection bias in the award of subsidies to firms that would anyway have been the most innovative (picking winners), this could imply an upward bias. There could also be an upward bias in the self-reported innovativeness measure. The gains relative to government outlays are also investigated, the conclusion being that SME innovation policy between 2002 and 2004 was efficient. The policy recommendation is therefore to continue such direct and indirect funding of innovation, though the R&D tax credit does not impact innovation significantly differently to direct subsidies according to these estimates.

For a recent survey of the empirical literature on the effectiveness of R&D tax credits, much of it looking at the firm or industry level, see Lokshin and Mohnen (2010) and HMRC (2010). The impact of tax credits on R&D spending is generally thought to be positive, though whether it is cost effective is controversial. Table 2 in the HMRC report (p. 16) illustrates the wide range of estimates for short and long- run elasticities of R&D spending with respect to its user cost or price, or estimated benefit-costs ratios; of course this range of estimates is obtained for varying samples of countries and time periods, and using different methodologies. An influential country-level study is Bloom et al. (2002). The impact of tax incentives on R&D intensity between 1979 and 1997 is estimated in a panel of nine OECD countries with fixed effects. Their estimate suggests that a 10% reduction in the user cost of R&D increases R&D intensity by 1% in the short run and around 10% in the long run. Contrasting firm-level evidence is provided by Bravo-Biosca et al. (2013), who find that tax incentives to R&D significantly reduce MFP growth using a difference-in-differences approach.

The UK R&D tax credit is very costly and evidence for its effectiveness on aggregate productivity growth is of great interest. See e.g. Rassenfosse and van Pottelsberghe (2009), Bouis et al. (2011) and Hall (2013) for evidence on the policy determinants of patenting and productivity growth. However, since the UK R&D tax credit has not spanned even half the sample period analysed in this thesis, we do not investigate this aspect of the R&D policy mix. Likewise, though policy surrounding patenting activity continues to receive much attention, this is beyond our scope here; therefore this evidence is only touched on briefly in what follows.

6.2.4 The Impact of R&D subsidies on Business R&D: Country-level Studies

Given the macroeconomic focus of the present study, we concentrate on the macro-econometric literature. There have been various country-level studies investigating the extent to which policies in support of R&D have stimulated innovation and productivity growth. We consider first some empirical evidence for a link between innovation policies and private sector R&D, with particular focus on direct subsidies.

Jaumotte and Pain (2005) look at a panel of 20 OECD countries from 1982-2001. Their model follows Hall and van Reenen (2000) in treating the aggregate R&D stock as an input to the aggregate production function and accumulating it from real expenditures in a manner analogous to the capital stock. This makes R&D demand a function of the real user cost of R&D; the user cost formula is based on the Hall-Jorgenson formula for the real user cost of fixed capital (see Hall and van Reenen, 2000, Appendix A) and is equivalent to the OECD B-Index, multiplied by the real interest rate plus the R&D depreciation rate (since the deflator used for R&D is the GDP deflator). They calibrate depreciation (the rate at which the R&D stock becomes obsolescent) at 11% from other literature, though robustness checks using 16% and 6% show the estimation results are not sensitive to this. Augmenting the R&D demand equation with various potential macroeconomic and policy factors, they estimate a dynamic error correction model with fixed time and country effects. The dynamic approach, including the lagged dependent variable, is common in the literature since Guellec and Van Pottelsberghe (2000) due to the high adjustment costs that characterise R&D activity. The approach distinguishes long-run from short-run effects.

Their results suggest that direct subsidies to business R&D as a proportion of GDP have a significant negative impact on business R&D intensity, though the effect of R&D subsidies as a share of corporate profits is positive. Intellectual property rights measured by the Ginarte-Park index do not affect business R&D stocks, though they increase patenting. The most important factors positively “determining” innovativeness in the study are the supply of high-skilled researchers, public sector research, links between business and universities, the degree of product market competition, the level of financial development and access to foreign inventions. A reduction in the user cost of R&D does raise business R&D, but the full effect takes many years to appear and its coefficient is sensitive to the model specification. A re-estimation of their main model using lagged variables at (t-2) to instrument current dated regressors potentially suffering from endogeneity has little impact on their estimates, leading them to conclude that bias is negligible.

Westmore (2013) is in part an extension of Jaumotte and Pain (2005) including more recent data. Thus the policy determinants of business R&D and patenting are investigated in a dynamic panel of 19 OECD countries spanning the mid-1980s to 2008 with fixed effects, again restricting the coefficients to be homogeneous across countries. Using accumulated real R&D expenditure and the number of new patents to proxy private sector innovation activity, he finds that tax incentives proxied by the OECD tax subsidy rate, direct subsidies to R&D and patent protection rights proxied by the Ginarte-Park index all have a positive and significant impact on these dependent variables in an error correction framework. Interestingly, the significance of real publicly funded business R&D in the business R&D regression seems to depend on the post-2001 data, as when the specification is re-estimated for the 1982-2001 sample (as in Jaumotte and Pain, 2005) the impact is no longer significant. The suggested explanation is that the context for direct subsidies has changed over time; formerly, OECD governments tended to subsidise projects for which they contracted to buy the output, so that subsidised private R&D would have substituted for/crowded out privately funded R&D, while more recent subsidy schemes have switched to a grant-matching format. The latter obliges the supported firm to increase its own R&D investment by an amount matching the size of grant received, in an attempt to ensure input additionality.

However, some earlier empirical work did find in favour of subsidy effectiveness on pre-2000 samples. Guellec and van Pottelsberghe (2000) find in a dynamic panel of 17 OECD countries between 1983 and 1996 that direct subsidies to business R&D generate additional business-financed R&D, as do tax incentives; that direct subsidies and tax incentives to business R&D are policy substitutes in terms of their impact on business R&D; and that more frequent changes in direct support and tax incentive programmes reduces their effectiveness in raising privately funded business R&D. They also find that there is a threshold for government subsidies beyond which the impact on business R&D becomes negative – so a non-linear relationship – though Westmore (2013) finds no evidence for a threshold of this nature.

Guellec and van Pottelsberghe (2000) note that although the presence of spillovers between treated and non-treated firms or industries makes it difficult to examine the impact of government policies on R&D in micro datasets, at the macroeconomic level this is not such a problem. They suggest that we can reasonably assume government policy to be exogenous to private sector R&D at this level (David et al., 2000), though they acknowledge potential latent variables –

i.e. a common unobservable driving both government spending on R&D and business spending on R&D – in the business cycle (which they control for by adding GDP growth as a regressor) and the cost of R&D. The latter was emphasized by Goolsbee (1998), who shows that prices of R&D inputs like skilled labour could go up in response to a government subsidy increase, due to restricted supply of these inputs; this would lead to an increase in business R&D expenditure in nominal terms only. They therefore attempt to correct for potential bias in their estimates arising from the response of R&D prices to demand changes, using Gooslbee's estimates. A three-stage least squares approach is adopted in which the first two stages are an instrumental variables procedure to account for the presence of the lagged dependent variable amongst the regressors, and the third stage addresses the possibility of cross-country correlations between same-dated residuals (a problem that OLS suffers from in this case). The reader is referred to their Annex 2 for country-level studies of the effects of subsidies on private R&D conducted prior to 2000 (there are not many); I only mention Levy (1990) whose results using a Box-Cox procedure suggest that effects vary across the 9 OECD countries he looks at, with a significant negative impact for the UK and the Netherlands in the 1963-84 sample, a positive impact in four other countries, and an insignificant result for the other two.

Falk (2006) investigates a dynamic panel model in which private sector R&D intensity depends on policy determinants including the generosity of tax incentives (represented by the B-Index), and direct subsidies to private R&D as a percentage of GDP, in addition to a matrix of controls. The sample comprises 21 OECD countries from 1975-2002, using 5 year averages, and the model is estimated using system GMM (Blundell and Bond, 1998), addressing endogeneity in the regressors by instrumenting them with their own lagged levels (differences) in a regression in differences (levels), though results from other estimators are also reported for comparison. The finding that tax incentives affect business R&D intensity significantly and positively is robust to variation in the model specification and estimation technique. However, direct subsidies are only significant using the first differenced GMM estimator (Arellano and Bond, 1991). This is not the preferred method for this context owing to the high persistence in the individual time series which leads to a loss of efficiency in estimation (Blundell and Bond, 1998);[3] business

[3] High persistence in the level of the variables means that lagged levels are weak instruments for first differences of the variables.

R&D intensity in particular is shown to be highly persistent, indicating its slow adjustment to changes in determinants. High tech exports as a proportion of total exports, likewise, is a significant, positive determinant of business R&D intensity only for the one-step first differenced GMM estimator. Intellectual property rights, represented by the Ginarte-Park index of patent rights, are not found to be significant in the dynamic panel model, though a significant effect is present in the static fixed effects model (again, this model is not preferred since the estimator is not consistent).

Cincera et al. 2009 take a different methodological approach, looking at the efficiency of public R&D expenditure in stimulating aggregate R&D in a group of 21 OECD countries with Data Envelopment Analysis and Stochastic Frontier Analysis. These methods require the construction of efficiency scores from input-output ratios; selected inputs include government subsidies to business R&D, while outputs include total private R&D expenditure. Their results are somewhat sensitive to the choice of estimation method, but general conclusions are that government subsidies to business R&D have successfully stimulated private R&D expenditure, and that efficiency scores depend positively on deregulation of labour and product markets, intellectual property rights, and the share of high-tech manufacturing, amongst other macroeconomic factors.

6.2.5 Aggregate Impacts of R&D, and R&D Policies, on Economic growth

The relationship between R&D and growth

Here I look first at the empirical evidence for a relationship between productivity and R&D, before turning to the growth impact of policies designed to stimulate R&D.

At the country level, estimates of the marginal effect of R&D on productivity will capture both the direct rate of return to R&D captured by the firm and the externalities generated for other firms as a result of spillovers in innovation outputs. Coe and Helpman (1995) and Park (1995) are early examples of a panel approach applied to large samples in both the country and times series dimensions. Both look at the question of whether private sector-conducted R&D affects returns at the aggregate level, Coe and Helpman for 22 developed countries between 1970 and 1990, and Park for 10 OECD countries between 1970 and 1987. Both find a positive and significant impact of R&D at the country level, though neither rigorously tests for cointegration as techniques were not fully developed at the time. If time series processes in the regression are non-stationary, the absence of a cointegrated relationship between them suggests spurious estimates.

Khan et al. (2010) estimate the impact of R&D stocks on total factor productivity in a cointegrated panel of 16 OECD countries, including human capital and a range of other potential non-R&D productivity determinants in order to test the robustness of the R&D-productivity relationship. Controls include ICT, high tech export and import ratios, inward and outward FDI stock ratios, the relative size of the services sector, public infrastructure, measures of financial development and a business cycle proxy (unemployment). Accumulating R&D stock variables for business, public sector and foreign R&D, they find all are positive and significant, a result that is robust to changes in model specification, to the measure of total factor productivity , and to the depreciation rates employed in the R&D stock calculations. The estimated point elasticity of TFP with respect to business R&D is between 0.017 and 0.174, lower than both public and foreign R&D elasticities, which are in the ranges 0.071-0.284 and 0.010-0.057 respectively. All non-R&D determinants are also found to be positive and significant when their joint effect is represented by the weighted principal component variable. They find cross-country heterogeneity in parameters by interacting variables with country-level average stocks of R&D; a higher stock of existing R&D raises the R&D elasticity for that country, and they find the same for human capital stocks. The three types of R&D stock also exhibit small complementarities when they are interacted together.

A Moving Block Bootstrap resampling procedure reveals the small-sample validity of their estimators. Their cointegration tests show all time series variables they use are non-stationary and that all their model specifications are cointegrated. Since their findings agree qualitatively with earlier studies where cointegration was not rigorously tested for, we might conclude that these relationships were cointegrated as well.

Erken et al. (2008) find in a dynamic panel for 20 OECD countries between 1971 and 2002 that the impact of private sector R&D on TFP growth is positive and significant, and robust in various specifications taken from the growth literature, and to the addition of alternative growth drivers including human capital. Their findings are of particular interest for this research, in that the estimated impact of business R&D is stable in magnitude and significance when entrepreneurship is added as a regressor (this is a measure of distance from equilibrium self-employment rates, constructed following Carree et al., 2002; see Chapter 4, Section 4.4.2). This result should emphasize that the hypotheses tested in Chapter 5 and 7 are not competing, but are different aspects within a systemic theory of growth. Both R&D and self-employment rates are significantly correlated with growth, and they appear to measure different channels to some extent.

Bravo-Ortega and Garcia Marin (2011) look at the direction of causation between R&D and productivity in a panel of 65 countries for 1965-2005. They note the failure of many studies of R&D and growth to take potential simultaneity and reverse causality into account. Given that R&D is strongly procyclical, R&D expenditure and productivity could both be responding to the same demand shocks. Equally, if R&D spending decisions are made on the basis of expected changes in output, this would imply reverse causality. Using a system GMM approach, they find that real per capita R&D expenditure "Granger causes" TFP in the sense of statistical precedence in time (Granger, 1969), while the reverse does not hold. However, Granger causality results are inconclusive for the relationship between other measures of R&D expenditure and TFP; these other measures include R&D in constant PPP US dollars, and R&D as a proportion of GDP (all measures are in logs). All three R&D measures are found to be weakly exogenous in the sense of Engle, Hendry and Richard (1983) but, as they note, this is not sufficient to rule out feedback from the endogenous to the weakly exogenous regressor; only R&D expenditure per capita is concluded to be strongly exogenous to productivity by means of the Granger causality results. Subsequent system GMM regression of TFP on per capita R&D expenditure and controls shows a positive and significant effect from R&D to TFP (level). They conclude that increasing expenditure in R&D per capita in the future will therefore increase TFP at the country level. This involves an explicit assumption that their regression model is invulnerable to the Lucas critique (Lucas, 1976); that is, that the underlying relationship between R&D and TFP in the historical data is not liable to change in response to a future policy change. They argue that "R&D and TFP are linked by a technical relationship that cannot be characterized as a decision policy function", so that the Lucas critique does not apply here and strong exogeneity is a sufficient condition for their policy recommendation (p.1093).

Other work in this vein is Guloglu and Tekin (2012), who examine the direction of causality between R&D, innovation and growth in a multivariate panel VAR for 13 high income OECD countries, 1991-2007. Their broad conclusions are that R&D activity (measured by R&D intensity) and technological change (proxied by the rate of patenting) Granger cause economic growth together, while economic growth and R&D investment together Granger cause economic growth. This implies support for both the science-push theory of growth (e.g. Aghion and Howitt, 1992) and the demand-pull hypothesis of Schmookler (1966) that technology is driven by the needs of consumers (and hence by income). Concerns about endogeneity in simple regressions of growth on measures of innovation or innovation policy would therefore seem to be justified.

Direct impacts of R&D policy on growth

Some early evidence on the aggregate impacts of R&D by source of funding is Lichtenberg (1992) who finds the elasticity of GNP with respect to government funded R&D is large, negative and significant, in a non-linear least squares estimation of a constant returns Cobb-Douglas aggregate production function. On the other hand, the elasticity of output with respect to privately funded R&D capital is positive, significant and around 7% (roughly one third of the return to the physical capital stock), and the social rate of return to private R&D investment is about seven times larger than the return to investment in buildings and equipment. Lichtenberg notes that endogeneity in the investment rates would render these results suspect. Also, since the results do not break down government funded R&D by sector of performance, there is no estimate of the impact of direct subsidies to business R&D. Much government-funded R&D is carried out with public good objectives that may not be well captured in GNP, such as health and defence; this type of publicly-funded R&D is more usually carried out by public sector institutions . Indeed many forms of government-funded R&D, such as government basic research and higher education R&D, have been found empirically to have near zero returns (e.g. Westmore, 2013). This is why we focus on government funding of business-performed R&D in the empirical work in Chapter 7.

Guellec and van Pottelsberghe (2004) regress total factor productivity growth on R&D capital by sector of performance (private sector, public sector and foreign firms) for a panel of 16 OECD countries between 1980 and 1998 in an error correction model. They find all three to be significant positive determinants of productivity growth in the long run. Their estimate of the long-run elasticity of TFP with respect to business R&D is 0.13, making the "social return" to business R&D "much higher than the 'normal private return"' (p. 366). The estimated long run elasticity with respect to foreign R&D is higher, at 0.45, giving a large role to absorptive capacity for international spillovers. Interacting the types of R&D by sector of performance with a time trend, they find that business R&D has grown in its impact on productivity during the sample, while public R&D has decreased in impact, confirming "the impression given by business reporting that R&D is an increasingly important activity for firms in a knowledge-based economy". They further analyse additional factors affecting the effectiveness of these types of R&D in causing productivity growth, finding that the source of funding matters for the effectiveness of private sector R&D in stimulating productivity. They find a negative impact on productivity growth of business R&D funded by government, though when this is decomposed by government objective this negative result seems to be driven by defence-related R&D subsidies; subsidies aimed at civilian R&D are weakly positively related to productivity growth.

Returning to Westmore (2013), he finds in a dynamic panel of 19 OECD countries that intellectual property rights, direct R&D subsidies and fiscal incentives to R&D are statistically significant determinants of R&D activity and patenting (as previously discussed), and those activities are found to be statistically significant determinants of Multi-Factor Productivity (MFP) growth in turn. However, when MFP growth is regressed on policy determinants directly they are insignificant, even when the channelling variables (R&D expenditure and patenting) are excluded from the specification. This is a strange result; we would expect an indirect effect of policy via the omitted 'growth driver' activities to show up in the estimates. Westmore suggests various explanations for this, including the possibility that these policies encourage sub-types of the broader 'innovative' activity measures that are actually not productive. For instance, tax incentives may stimulate types of project with a low marginal value. The same may be true of direct subsidies; this would be more surprising given that subsidies "are thought to be targeted at R&D activities with high social worth, but may highlight the information asymmetries that are often seen as a reason against such government intervention" (p.31). Likewise, intellectual property rights may simply increase the propensity to patent, rather than increasing productive innovation.

Alternatively, the policies may stimulate genuinely innovative activities but the productive impact of these activities may simultaneously be neutralised by other productivity-dampening effects. The most obvious suggestion in this context is for intellectual property rights which, while potentially enhancing incentives to innovate, endow incumbents with market power, so reducing competition. Bravo-Biosca et al. (2013) find a similar entry barrier effect arising from R&D tax incentives.

The evidence from cross-country growth regressions has been duly represented here but, as discussed in Chapter 4, there are those who question its value. Mankiw wrote in 1995 that "[p]olicymakers who want to promote growth would not go far wrong ignoring most of the vast literature reporting growth regressions. Basic theory, shrewd observation, and common sense are surely more reliable guides for policy" (1995, pp. 307-308). We may wonder whether the methodology has moved on by now to the point where this remark is no longer justified. It seems that a certain number of important objections to this literature remain, in spite of attempts to address them. Temple (1999), Durlauf et al. (2005) and Easterly (2005) between them point out potential biases or lack of robustness due to parameter heterogeneity, outliers, omitted variables, model uncertainty, measurement error in regressors and, finally, regressor endogeneity. In the policy-growth literature the regressor we suspect of endogeneity is the policy variable, since policies are frequently a response to economic conditions. Such endogeneity will bias the estimated impact of the regressor, also undermining identification as we cannot know the causal relationship underlying the results.

Rodrik (2012) gives a rigorous example of how the endogeneity inherent in regressions of growth on policy variables renders them uninformative for the policy questions that motivate them. Using the example of La Porta et al. (2002), he shows that the reduced form regression model they estimate of productivity growth on government ownership of banks could be derived from several distinct structural models (or underlying theories), making the interpretation of their results ambiguous. In other words, their regression model is not identified. The argument is as follows. La Porta et al. contrast two hypotheses which they call 'developmental' and 'political', respectively. According to the former, state ownership is a response to market failures and is a catch-up strategy; the latter holds that state ownership is a mechanism for political favours to pass between government and vested interest groups. Finding a negative correlation between ownership (the regressor of interest) and productivity growth, they infer that the political perspective is upheld by the data, rejecting the developmental explanation for state ownership. Rodrik points out that the 'independent' variable, government bank ownership, has different drivers depending on the hypothesis, each of which would be unobservable. Under the developmental hypothesis, state ownership is driven by the extent of the market failure, while under the political hypothesis it is driven by the government's level of corruption. Since in either case the regressor is correlated with an unobservable factor, the omitted variable bias cannot be corrected by adding another observable co-variate to the right hand side, nor will splitting the sample address the problem (both strategies used by the authors). Moreover, since we do not have the counterfactual (what would have been the growth outcome had the government not intervened?), we cannot accurately evaluate the impact of the policy. A benign government will observe a market failure and intervene more extensively using policy; if the market failure is reduced to some extent as a result, but not removed entirely, we will still observe a relatively poor economic performance in conjunction with the policy. Consider another country which does not suffer from market failures and therefore does not use the policy intervention; this country performs well economically on average throughout the sample period (the regression is conducted for averaged growth rates only) so again there is a negative relationship, as healthy growth is associated with less policy intervention. Thus the developmental hypothesis is equally well borne out by the estimation results, if policy intervention is itself driven by market failure (which also drives poor performance).

Though the faults of growth regressions are widely recognised, they are often defended on the grounds that "they help us update our priors about the impact of certain types of policies" (Rodrik, 2012, p. 141) and that "even simple or partial correlations can restrict the range of possible causal statements that can be made" (Wacziarg, 2002, p. 909). However, when models are not identified it is not at all clear that this is defensible. Rodrik writes that "there has been relatively little discussion of the consequences of policy endogeneity" in the aggregate growth regression literature, even amongst its critics, which he finds surprising given the attention paid to the issue in microeconometric studies. While selection bias in policy evaluation studies at the micro level can be addressed using instrumental variables or randomised trials, he argues that neither of these strategies is readily applicable at the country level. Evidently nations cannot submit to random policy experiments and finding credible instruments which are relevant (related to policy), exogenous (uncorrelated with the unobservable determinants of the dependent variable) and do not belong in the second stage of the regression is "genuinely hard" in this context (p. 148; cf. also Durlauf et al. 2005).

The next step is, he says, to "take the theories that motivate our empirical analyses more seriously. Our failure to undertake meaningful tests often derives from a failure to fully specify the theoretical model(s) being put to the test" (p.148). We must specify a model that embeds the null hypothesis we are testing, "come clean about what we assume is and is not observable, and inquire whether the empirical implications of such a model are consistent with the data" (p. 148). This is where the DSGE model approach used in the present study has something to offer. The Indirect Inference Wald test does precisely what Rodrik advocates: the simulated data generated using the bootstrapped model (which embeds the policy-driven productivity growth hypothesis) are formally compared to the historical data through the auxiliary VECM, the closeness being summarised in the Wald statistic.

6.2.6 Simulation-Based Analysis

There are other studies using a DSGE simulation approach to analyse the macroeconomic impact of R&D policies. One example is McMorrow and Roeger (2009), who look at the relationship between R&D policies and economic growth in a global DSGE model calibrated to the EU and to the US. They use the European Commission's QUEST III model (Ratto et al. 2009) embellished with the semi-endogenous growth mechanism in Jones (1995b), which adapts the Romer (1990) product-variety model by assuming diminishing returns to the R&D stock input in the knowledge production function where Romer assumes constant returns. The semi-endogenous growth assumption is thought to be more consistent with the stylized facts of long-run growth than pure endogenous growth, which would have predicted large long-run growth responses to changes in policy trends over time in contrast with the stable growth rates that have been observed (Jones, 1995a). As such, in this model policy reforms can only generate a permanent change in the level of GDP rather than in the long-run growth rate.[4]

QUEST III is a New Keynesian DSGE model, much like the IMF's Global Economy Model (Bayoumi et al. 2004) and the European Central Bank's New Area-Wide Model (Christoffel et al. 2008), featuring real, nominal and financial frictions which help to generate behaviour consistent with the data (cf. Smets and Wouters, 2003). In this extension of QUEST III, the R&D sector uses the existing R&D stock and highly skilled labour to generate patents for new varieties of intermediate goods; these patents are licensed and used in production by intermediate goods firms; intermediate goods are in turn used in production in final goods sector, with productive efficiency increasing with the number of input varieties. Since the model setup implies externalities due to monopolistic competition in final goods and intermediate goods sectors, and spillovers from existing knowledge stocks, there is insufficient investment in knowledge in a market outcome. So there is a role for policy intervention built into the model due to market failure – the study is a quantitative comparison of different policy reforms relative to the baseline. Barriers to start-up act as a structural friction in the innovation process, while tax credits to R&D reduce the sunk cost incurred by the intermediate goods producer licensing a newly generated idea for production. They also assume a distribution of skills in the workforce, with only high-skilled labour able to move between production and research sectors. The EU rate of return to R&D is calibrated at 0.3 since this is the mid-point of the studies that they review, slightly above returns to other corporate investments.

Thus McMorrow and Roeger start with a "stylized fact of a significant under-investment in knowledge capital in the EU", and then, using a model in which this hypothesis is embedded, examine the responses of macroeconomic aggregates to certain policy reforms thought to stimulate R&D. The reforms looked at are: a direct subsidy (or tax credit) to R&D spending; a reduction in barriers to entry (i.e. an indirect policy measure) in the form of lower administrative costs and increased access to finance for start-up firms; and policies to increase the supply of high-skilled workers in the research sector. They find that increasing the EU R&D tax credit to the US level raises R&D spending by about 0.1% of GDP after 20 years. In other words, direct subsidies to R&D can make only a "modest" contribution to productivity growth

[4] The semi-endogenous growth assumption is frequently adopted in this sort of Central Bank model because of its greater ability to fit the stylized facts in the data.

(p.113). This is because the supply of high-skilled workers is constrained, meaning that much of the impact of the subsidy to R&D spending is absorbed by an increase in the researcher wage (cf. Goolsbee, 1998); and also because of the declining marginal efficiency of skilled labour in the knowledge production function, due to the semi-endogenous growth assumption. In the short run there is reallocation of high-skilled labour from the production sectors to the research sector, which has a dampening effect on output in the periods directly following the reform (this is the case in the model proposed in this paper as well).

The other two policies investigated – the reduction of entry barriers and human capital improvements – both have a more stimulating effect on R&D intensity and hence growth than the fiscal stimulus, though "measures would have to be substantial" (p.113); setting EU entry costs at US levels according to the estimates of Djankov et al. (2002) only closes 20% of the productivity gap in the long run. Of course, though the paper does not investigate it, combinations of these policies might generate complementarities. For instance, human capital policies in conjunction with the tax credit would reduce the crowding out effect that dampens the fiscal policy impact, by increasing the pool of high-skilled workers and so enhancing the tax credit's effectiveness. These findings are borne out in Roeger et al. (2009, 2010) using a similar model setup.

Other macro-simulation studies follow a similar procedure, investigating the quantitative impacts of various policy reforms relative to a baseline when the qualitative responses of the model are essentially fixed by the setup and the calibration. However, there are few (if any) studies in which the DSGE model's performance is compared to the historical data in a formal frequentist test. Hence these studies merely illustrate the modellers' assumptions, with no test of their accuracy.

Note on the Model in Chapter 2 as a Testing Vehicle for Policy Incentives Surrounding R&D

In Chapter 7, the model presented in Chapter 2 is set up with subsidy variable s_t' as a systematic driver of next period's productivity level. This relationship is derived through the representative agent's utility optimisation with respect to z_t, a measure of the time spent in some innovative activity which is directly incentivised by government, whereas in the empirical work that follows, the policy variable is represented in the data by subsidies to private firm expenditure in R&D; this is therefore strictly an incentive to R&D as a firm-level choice. R&D is generally modelled as the choice variable of the firm, but not here – the theoretical distinction between firm and supplier of inputs to production is an abstraction necessary to maintain the assumption of perfect competition in this model. Thus z_t is perhaps more analogous to the agent's decision to supply skilled labour to the firm for research. It could be argued that subsidies to firm R&D expenditure lead the firm to raise wages to skilled workers, so incentivising the agent to spend more time in research. However, z_t is notionally conducted outside the firm in the world of the model.

There is no suggestion that the model in Chapter 2 is an ideal microeconomic representation of the R&D process.[5] Rather than equating time spent in z_t literally with R&D activity as that is defined in the data, this variable should be viewed as a conceit allowing us to derive a reduced form relationship between R&D policy and productivity growth. The model is designed to isolate policy drivers and their macroeconomic effects. Thus the emphasis is on the aggregate relationships derived from the microfoundations, between the policy variable incentivising what we loosely call 'R&D' and the productivity growth rate.

6.3 Conclusion

This chapter has reviewed some theoretical and empirical literature on the policy determinants of private sector R&D, on R&D determinants of productivity growth, and on direct relationships between R&D policy and productivity growth, focusing mostly on direct subsidies. The theoretical literature gives diverse policy recommendations and to choose between these an empirical consensus would be helpful; however, a reliable consensus has not really emerged. The empirical literature is interesting but has serious flaws, mainly due to lack of identification. Once again, micro-level studies do better at overcoming this issue than macroeconometric studies, but they are not informative on the macro-level phenomena we are interested in. The macroeconometric growth literature is still largely vulnerable to Mankiw's pronouncement that "Policymakers who want to promote growth would not go far wrong ignoring most of the vast

[5] It may indeed be rather inappropriate for the study of R&D incentives at a granular level - but then this is a criticism levelled at DSGE models in many dimensions; nevertheless, we do not discard them.

literature reporting growth regressions. Basic theory, shrewd observation, and common sense are surely more reliable guides for policy" (1995, pp. 307-308). Rather than abandoning all hope of a legitimate empirical understanding of the issues, another approach is desirable. We therefore set up an identified, if abstract, model designed to test the efficacy of R&D subsidies at stimulating growth in the UK between 1981 and 2010. This model is tested and estimated by Indirect Inference in the next chapter.

Chapter 7

Testing and Estimating a Model of UK Growth Driven by R&D Subsidies

7.1 Data for the Policy Variable

Data constraints require us to focus on the post-1981 period only for the R&D channel. The policy variable used in this chapter is the ratio of business-performed R&D expenditure (BERD) financed directly by government, to the total level of BERD (all sources of funding)[1]. This is referred to below as the subsidy rate. Aggregate data on BERD is available annually between 1981 and 2010, with missing values at 1982 and 1984. Each missing value has been interpolated as the arithmetic average of the two contiguous values. Robustness checks have been conducted around the interpolation of these missing values and are reported below. The ratio obtained at annual frequency is interpolated to a quarterly frequency using a constant average match interpolation. The ratio is plotted in Figure 7.1 for the constant average and quadratic average interpolations.Here, the policy examined is a subsidy to the presumed growth driving activity (business-conducted formal R&D), and the hypothesis is that the impacts of policy on z_t and of policy on $D \ln A$ are both positive: $c_1 > 0$ and $b_1 > 0$. The subsidy variable, with a linear

[1] Source: OECD (2014).

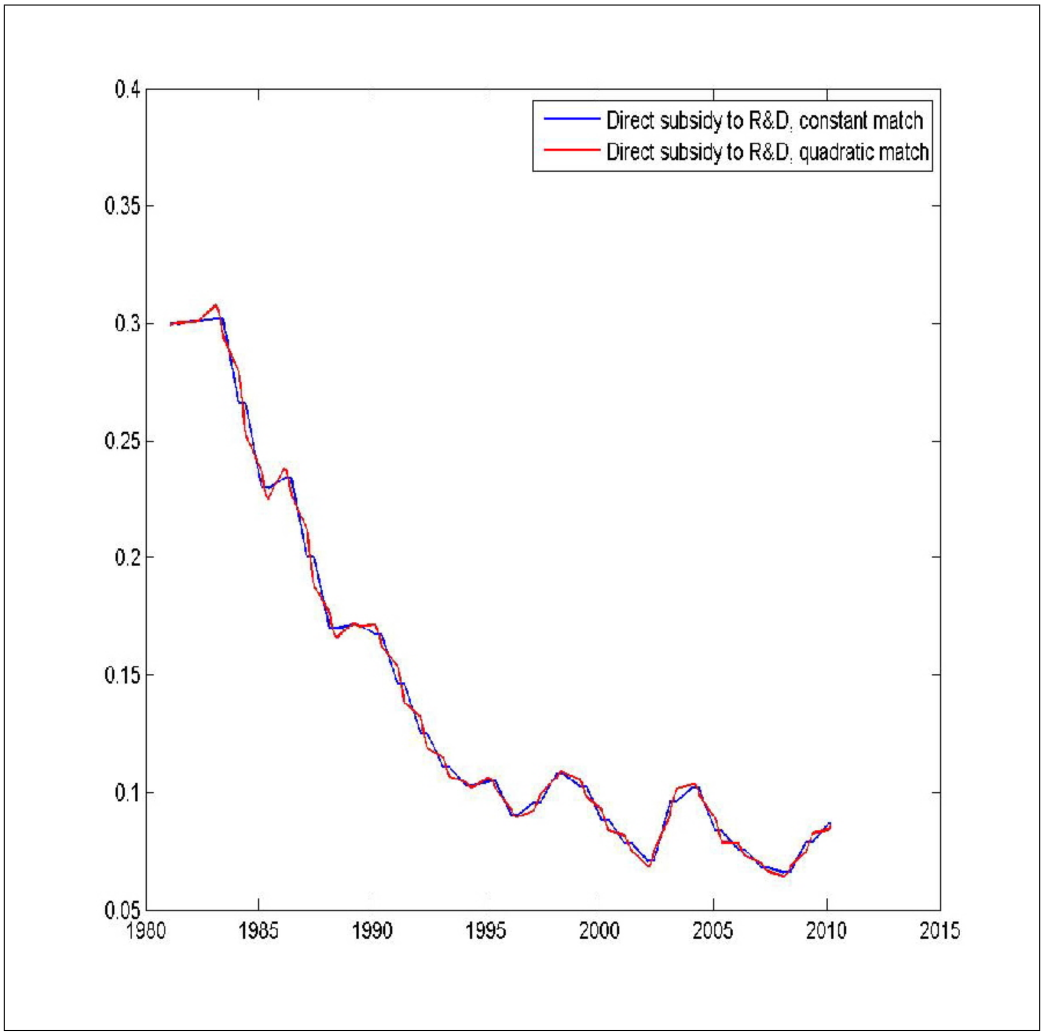

Figure 7-1: Business R&D Subsidy Variable. Ratio of Government Funded BERD to Total BERD. Source, OECD

trend and constant removed, is plotted against the log difference of the Solow residual in Figure 7.2. It is interesting to contrast this plot with the relevant part of Figure in Chapter 5; the time series behaviour of this policy variable is quite different to $\tau(1)$ during the period from 1981. Also, the variance of the productivity growth series in this shorter sample is much lower. Due to the attention paid in the literature to adjustment inertia in the response of R&D to policy determinants (Guellec and van Pottelsberghe, 2000; Westmore, 2013), I have also tested and estimated the model with a 4 quarter lag in the subsidy rate, whereas the baseline model assumes a 1 quarter lag. This reduces the sample size further, relative to the analysis in Chapter 5. Results are therefore reported in this Chapter for two models, both using the subsidy rate as the policy driver.

1. SUBS Model 1: The model in Chapter 2, with productivity process $\ln A_t = \ln A_{t-1} + b_0 + b_1 s'_{t-1} + e_{A,t}$
2. SUBS Model 2: The model in Chapter 2, with productivity described as $\ln A_t = \ln A_{t-1} + b_0 + b_1 s_{t-4} + e_{A,t}$.

The choice of starting value for b_1 in the R&D subsidy-driven model was already discussed in the calibration section of Chapter 2. There it was concluded that the empirical literature allows for considerable freedom around this choice, and around the choice of c_1. Starting values chosen for these are 0.1 and 0.06 respectively Note that the Indirect Inference Estimation procedure in Section 7.2.2 below should indicate if this starting point is far wrong. The estimation proceeds by searching across the parameter space for the set of coefficient values that minimises the Wald percentile. A preliminary to the search is the setting of bounds on that parameter space, and these have been set at 30% either side of the baseline calibration. If the starting value of b_1 is inappropriate, the estimation process will move towards one of the initial bounds, indicating that the search bounds should be shifted.

Since the R&D subsidy variable does not include fiscal incentives to R&D, which have increased in the UK since 2000, it is only a partial proxy for the policy incentives to R&D. However, fiscal incentives as measured by the OECD B-Index may affect R&D and productivity growth differently to direct subsidies (e.g. Foreman-Peck, 2013), so it is not immediately clear that we should combine them into a single index. Likewise, no indicator of policy surrounding

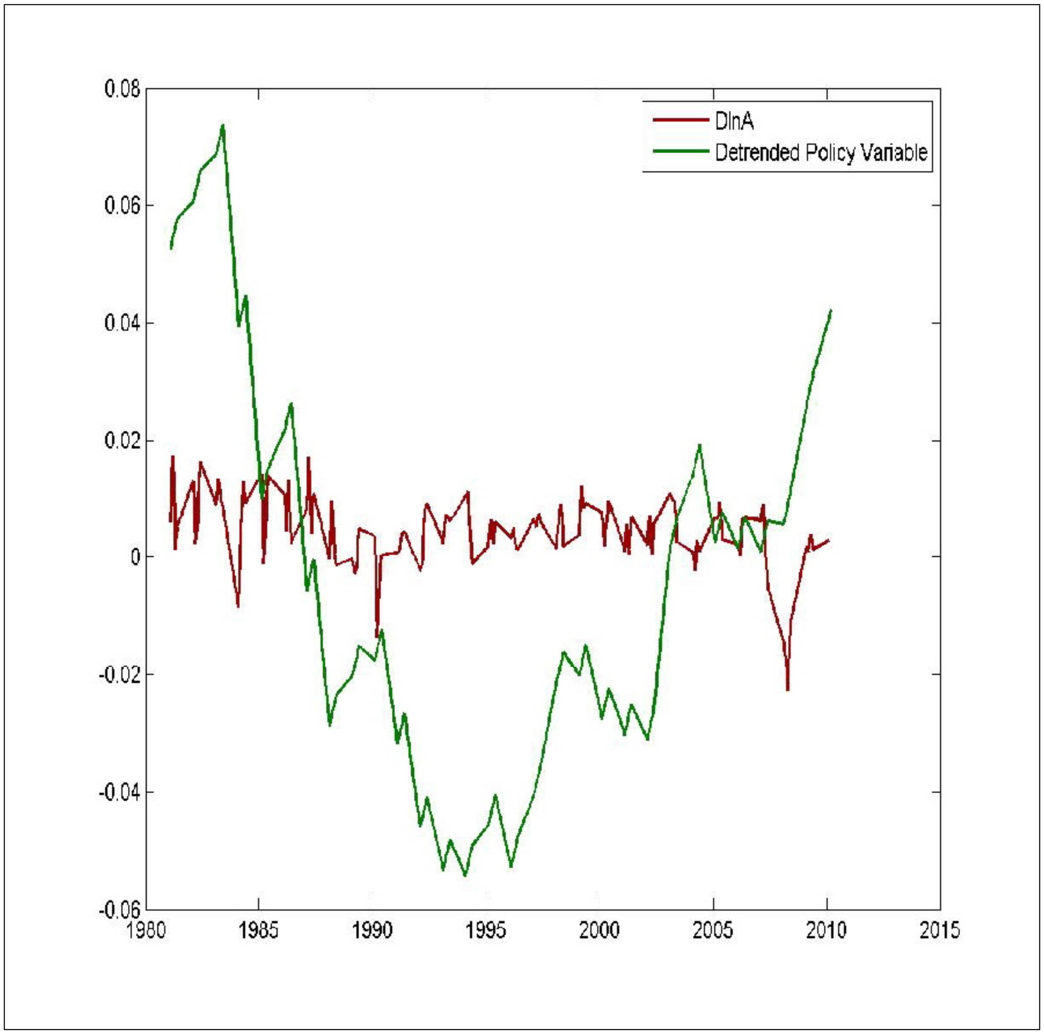

Figure 7-2: Linearly Detrended Subsidy Variable and $D \ln A$

$\boldsymbol{\rho}_1$	$\boldsymbol{\theta}_0$	$\boldsymbol{c}_1$	$\boldsymbol{\rho}_2$	$\boldsymbol{\omega}$	$\boldsymbol{\sigma}$	$\boldsymbol{\sigma}_F$	$\boldsymbol{\omega}_F$	$\boldsymbol{\zeta}_1$	$\boldsymbol{\zeta}_2$	$\boldsymbol{\zeta}_3$	$\boldsymbol{\zeta}_4$	$\boldsymbol{b}_1$
1.0	0.5	0.06	1.2	0.7	1.0	0.7	0.7	0.51	0.47	0.02	0.25	0.1

Table 7.1: Starting Parameter Values

$\mathbf{e}_r$	0.860	$\mathbf{e}_M$	0.848
$\mathbf{e}_A$	0.589	$\mathbf{e}_s$	0.974
$\mathbf{e}_N$	0.897	$\mathbf{e}_{CF}$	0.939
$\mathbf{e}_K$	0.765	$\mathbf{e}_{rF}$	0.851
$\mathbf{e}_{wh}$	0.879	$\mathbf{e}_G$	0.972
$\mathbf{e}_X$		0.939	

Table 7.2: AR(1) Coefficients for Structural Shocks to Variables Indicated by Subscript. Subsidy Model 1, Starting Calibration

intellectual property rights has been discovered spanning a long enough time frame for this investigation, and the little time series variation within a single country makes such an indicator uninformative. We could resort to patent counts to proxy innovation policy, but a) these are an outcome and may not be a good proxy for policy and b) they respond in a way that may have nothing to do with productivity (there is a large literature on the appropriateness of patents as a measure of innovation, see e.g. van Pottelsberghe, 2011). For these reasons, the subsidy variable employed here is preferred.

7.2 Empirical Work

In this chapter we investigate whether direct subsidies to business-performed R&D also play a role in causing productivity growth, in addition to the other drivers of productivity wrapped into the error, including barriers to entrepreneurial entry examined in Chapter 5. All fixed parameters in the calibration in this section are the same as Chapter 5, Table 5.6.

7.2.1 Indirect Inference Test Results (Baseline Calibration)

The baseline calibration for the structural coefficients are given in Table 7.1. The implied AR(1) coefficients in the stochastic processes are given in Table 7.2.

The test results for this calibration are given for both subsidy models in Table 7.3, based on the auxiliary VECM with output and productivity as endogenous variables (see Chapter 3,

Model	Normalised Mahalanobis Distance, VECM1
SUBSModel1	3.6293
SUBSModel2(lagged)	4.1358

Table 7.3: Wald Test Results, Baseline Calibration

ρ_1	θ_0	c_1	ρ_2	ω	σ	σ_F
0.9712	0.5267	0.0632	1.5198	0.5431	0.7676	0.8522
ω_F	ζ_1	ζ_2	ζ_3	ζ_4	b_1	$Wald\%$
0.8819	0.6359	0.3349	0.0240	0.2360	0.0901	77.04

Table 7.4: Wald Minimising Coefficient Values, Subsidy Model 1

Section 2). The normalised transformed Mahalanobis Distance statistic is 3.6293, indicating that the model is strongly rejected. The statistic falls in the 100th percentile of the Wald distribution. The test similarly rejects the second model, with a test statistic of 4.1358. Lagging the policy variable by four quarters in the productivity process appears to worsen the model's performance, when it is evaluated on output and productivity according to the baseline auxiliary model.

7.2.2 Indirect Inference Estimation Results

The structural coefficients are estimated by Indirect Inference; the simulated annealing algorithm searches within 30% either side of the starting coefficient values in Table 7.1. For Subsidy Model 1, the Wald percentile was minimised for the coefficient set shown in Table 7.4; the implied AR(1) coefficients for the shock processes are given in Table 7.5. Assessed on output and productivity, the normalised transformed Mahalanobis Distance statistic is 0.7358; the statistic falls in the 77th percentile of the Wald distribution. Therefore the model is comfortably not

$\mathbf{e}_r$	0.858	$\mathbf{e}_M$	0.832
$\mathbf{e}_A$	0.577	$\mathbf{e}_s$	0.974
$\mathbf{e}_N$	0.897	$\mathbf{e}_{CF}$	0.939
$\mathbf{e}_K$	0.951	$\mathbf{e}_{rF}$	0.851
$\mathbf{e}_{wh}$	0.837	$\mathbf{e}_G$	0.972
$\mathbf{e}_X$		0.939	

Table 7.5: AR(1) Coefficients of Structural Shocks, Subsidy Model 1, Given Estimated Coefficients

rejected on this auxiliary model (VECM 1). As in Chapter 5, some coefficients have moved some way from their starting values. Indeed, when the model is assessed on output and productivity alone, the Wald-minimising coefficients are very close to the set found for the $\tau(1)$ model in which productivity is driven by labour market regulation and top marginal income tax rates. Only b_1 and c_1 are different in absolute magnitude, as we might expect given the different policy variable driving the model here. This implies that the same structural model can accommodate the policy drivers in Chapter 5 as in Chapter 7.

A variance decomposition for the model with this coefficient set is reported in Table 7.6. As in Chapter 5, we can clearly distinguish this model from an exogenous productivity growth model; the endogenous variables respond considerably to the identified subsidy shock, not just to the separate productivity shock.

	r	**Y**	**N**	**K**	**C**	**w**	$\mathbf{w}'$	**X**	**M**	**Q**	$\mathbf{b}^F$	**A**	**d(A)**
e(r)	0.16915	0.00197	0.00946	0.01392	0.04238	0.03864	0.00063	0.01232	0.06000	0.01156	0.03056	0	0
e(A)	0.23125	0.34965	0.22750	0.21159	0.23919	0.11268	0.35403	0.31997	0.14627	0.30031	0.01221	0.37125	0.90164
e(N)	0.03092	0.00198	0.01529	0.00104	0.00167	0.02777	0.01385	0.00073	0.00006	0.00069	0.00074	0	0
e(K)	0.16036	0.02454	0.04456	0.41922	0.02423	0.01442	0.01927	0.01438	0.00731	0.01350	0.01233	0	0
$\mathbf{e}(\mathbf{w}')$	0.12176	0.01992	0.16159	0.01146	0.01462	0.03621	0.00125	0.00653	0.00058	0.00613	0.00491	0	0
e(X)	0.03448	0.01006	0.10313	0.00026	0.16463	0.44235	0.00103	0.10006	0.37763	0.14460	0.65353	0	0
e(M)	0.02802	0.00123	0.01439	0.00062	0.02004	0.03956	0.00022	0.01404	0.09832	0.01318	0.05384	0	0
$\mathbf{s}'$	0.14243	0.58885	0.40561	0.33892	0.41954	0.15387	0.60936	0.50078	0.17308	0.47001	0.09621	0.62875	0.09836
$\mathbf{C}_F$	0.00527	0.00159	0.01643	0.00006	0.06412	0.11844	0.00017	0.02681	0.12097	0.03590	0.13144	0	0
$\mathbf{r}_F$	0.07095	0.00009	0.00053	0.00285	0.00928	0.01594	0.00016	0.00423	0.01577	0.00397	0.00392	0	0
G	0.00539	0.00012	0.00150	0.00006	0.00030	0.00014	0.00002	0.00013	0.00001	0.00013	0.00031	0	0

Table 7.6: Variance Decomposition, Subsidy Model 1

Aux. Model	**(1)**	**(2)**	**(3)**	**(4)**
Endog	Y, A	Y, A, r	Y, A, Q	Y, A, K
Exog (included in test)	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}
Exog (excluded from test)	*trend*, *const*	*trend*, *const*	*trend*, *const*	*trend*, *const*
Wald percentile	77.04	100	100	96.63
Aux. Model	**(5)**	**(6)**	**(7)**	**(8)**
Endog	Y, A, N	Y, A, C	Y, A, r, Q	Y, A, N, C
Exog (included)	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}	τ'_{t-1}, b^f_{t-1}
Exog (excluded)	*trend*, *const*	*trend*, *const*	*trend*, *const*	*trend*, *const*
Wald percentile	100	100	100	100

Table 7.7: Wald Test Results, Alternative Auxiliary Vector Error Correction Models

As we would expect, the shocks entering non-stationary productivity process are generating most of the variance for each of the endogenous variables in this finite sample. However, the policy shock is less dominant than in Chapter 5, Table 5.12. The subsidy shock accounts for less of the change in the Solow residual than $\tau(1)$ did: 9.8% here, against 18.5% for $\tau(1)$. This is of course a result of the lower b_1 estimate found in the search process for this model; 0.09 here, while in Chapter 5 b_1 was estimated at 0.12. A direct comparison of these magnitudes is perhaps not justified, since $\tau(1)$ is composed partly of indices while the subsidy variable is a ratio of expenditures. However, the labour market indices are interpolated using the trade union membership rate, and they are also combined with the top marginal tax rate in $\tau(1)$. Therefore both $\tau(1)$ and the subsidy variable have the dimension of rates. Moreover, their descriptive statistics show that the linearly detrended series do not differ much in terms of their minimum, maximum and standard deviation (Table 9.2, Appendix 2). Direct comparison may therefore be appropriate. Here we find that a 1 percentage point increase in the ratio of government funded BERD to total BERD this quarter would increase productivity growth between this quarter and the next by 0.09 percentage points. As such an increase would be highly persistent within the policy variable, the growth effect would continue for some time in the future, though it would not be permanent. The level effect would of course be permanent (see Impulse Response Functions, Chapter 2, Figures 2.1 to 2.3).

Table 7.7 compares the Wald percentiles obtained for the baseline auxiliary VECM (VECM 1) to various other auxiliary VECMs, to examine the model's ability to capture the behaviour of other key endogenous variables.

Comparison of these results to those in Table 5.13, Chapter 5, shows that the model driven by the subsidy to business R&D performs as well as the model driven by the $\tau(1)$ series when examined on output and productivity alone. When the auxiliary model is expanded to include other endogenous variables, the model is rejected at the 5% significance level in all cases. The R&D subsidy-driven model's performance is less convincing when assessed on these extra dimensions.[2]

This does not necessarily reflect the shortcomings of the hypothesis that R&D policy drives non-stationary productivity and hence economic aggregates. We mentioned previously that the model's microfoundations may be less appropriate for the incentives surrounding the R&D process than for 'entrepreneurial' incentives. Hence the focus on VECM 1, which isolates the macroeconomic impact of the direct R&D subsidy on output and productivity alone; it is perhaps not fair to demand too much of this as an R&D model. Furthermore, we cannot rule out the possibility that $\tau(1)$ impacts business R&D incentives as well as what we have termed 'entrepreneurial' activities; the model setup cannot distinguish between these two channels, if indeed it is appropriate to think of them as different channels at all given their extensive overlap in practice. This is particularly the case when we consider a broader definition of research as e.g. Aghion and Howitt's (1998),[3] which would not exclude the research activities of innovative start-ups to the extent of formal BERD statistics; R&D expenditure figures significantly under-report innovation in the services industries and among SMEs (Foreman-Peck, 2013). We also referred earlier to studies such as Griffith and Harrison (2004) and Aghion et al. (2009) which have linked product and labour market regulation to manufacturing productivity growth empirically through the R&D channel. Therefore the tests carried out here do not imply a dichotomy between entrepreneurship and R&D as drivers of growth.

These are not competing hypotheses but are different pieces of the same puzzle, as suggested in other theoretical and empirical work. Miccelachi (2003) proposes a model in which both entrepreneurship and R&D are necessary for innovation; whether innovation is at its optimal rate depends on deployment of skilled labour between these two sectors in the correct proportions.

[2] Other 4 variable combinations were also tested, but are not reported here, since for all the Wald test statistic fell in the 100th percentile.

[3] "when we refer to 'research' or to 'R&D,' what we have in mind is the whole range of inputs to innovation, not just the small part that is actually captured in formal R&D statistics." (Aghion and Howitt, 1998, p. 8)

$\boldsymbol{\rho_1}$	$\boldsymbol{\theta_0}$	$\boldsymbol{c_1}$	$\boldsymbol{\rho_2}$	$\boldsymbol{\omega}$	$\boldsymbol{\sigma}$	$\boldsymbol{\sigma_F}$
0.7156	0.5657	0.0480	1.0674	0.7988	0.9380	0.5009
$\boldsymbol{\omega_F}$	$\boldsymbol{\zeta_1}$	$\boldsymbol{\zeta_2}$	$\boldsymbol{\zeta_3}$	$\boldsymbol{\zeta_4}$	$\boldsymbol{b_1}$	***Wald%***
0.7344	0.6191	0.3502	0.0198	0.1981	0.0969	94.48

Table 7.8: Wald Minimising Coefficient Values, Subsidy Model 2

A conducive environment for start-up may also be conducive to R&D, for businesses of any size; alternatively, R&D from large firms may spill over more effectively via start-up activity when the policy environment has fewer regulatory and tax-related disincentives, as in the knowledge spillover theory of entrepreneurship (Acs et al. 2009). Erken et al. (2008) find both entrepreneurship and R&D investments are significant determinants of TFP growth.

The results in this study as a whole indicate that both framework policies, such as the reduction of labour market frictions (due principally to trade unionism) and the reduction of marginal tax rates on personal income at the top of the distribution, and direct government subsidies to business performed R&D are significant drivers of output and the productivity level. We find that the model driven by framework policies is able to account for more dimensions of the observed UK experience jointly than the R&D subsidy-driven model, though the R&D analysis is based on a shorter sample and so the results are not directly comparable. Indeed, the results reported in this chapter for the subsidy-driven model constitute much weaker evidence than the results reported in Chapter 5 for the model driven by barriers to entrepreneurship. The R&D subsidy model performs well only when judged on the most parsimonious auxiliary model, and is rejected for all endogenous variables besides output and productivity. Thus while the conclusion is not to discard the R&D subsidy-driven growth hypothesis, it seems that this hypothesis when embedded in the Chapter 2 model is less convincing than the other. Future work will focus on testing this policy determinant when R&D incentives are modelled with more appropriate microfoundations.

We also find little evidence of lags in the impact of R&D subsidies on productivity growth. The 'best fit' coefficient set for the lagged model is reported in Table 7.8. The transformed Mahalanobis Distance statistic is 1.633, falling in the 94th percentile of the bootstrapped Wald distribution. This implies a borderline non-rejection of the model at the 5% significance level. Note that the coefficient estimate on the policy variable b_1 is very similar to the estimate in

Subsidy Model 1, though the other coefficient estimates differ quite substantially.[4] When this model is assessed on additional endogenous variables, it is strongly rejected across the board. These results suggest that the assumption of a 4-quarter lag between a change in the subsidy policy and its impact on the change in productivity is not appropriate for this UK sample. It may be that a lag length other than 4-quarters would be better, and this could be something to look at in further work.

Robustness checks showed the results for Subsidy Model 1 to be invariant to the interpolation technique (quadratic versus constant) and to the way in which missing values were supplied for years 1982 and 1984.[5]

7.3 Summary

In this chapter, the Chapter 2 DSGE model of the UK has been tested and estimated using Indirect Inference when productivity is driven endogenously by direct subsidies to private sector R&D, for the period $1981 - 2010$.

After Indirect Inference estimation, the model is comfortably not rejected by the Indirect Inference Directed Wald test for the basic auxiliary model, including output and productivity as endogenous variables. The estimated impact of current direct subsidies to private R&D on total factor productivity growth one-quarter ahead is 0.09, signifying that in this sample a 1 percentage point increase in the ratio of government funded BERD to total BERD raises short term growth in productivity by 0.09 percent per quarter, with permanent effects on the level.

This provides additional information on the impact of policy on growth in the UK since the 1980s. Since the policy variable consists of government-funded formal R&D activity, there is little doubt that this policy works on growth through the channel of formal R&D undertaken by firms, the majority of which are large and established, though this proportion has fallen over the sample period. Taken together with the findings in Chapter 5, the conclusion is that government policy has had an impact on the UK productivity experience, both through direct

[4] ζ_3 is somewhat lower than the constraint $\zeta_3 = 1 - \zeta_1 - \zeta_2$ would indicate (0.019 as opposed to c. 0.03), though not by much.

[5] Missing values were calculated as i) the average of two contiguous values, ii) equal to previous value, iii) equal to following value. The Wald test result was similar for all three.

subsidies to R&D, and more indirectly by reforming the policy environment in which firms (both new and established) make decisions.

We should note that, though this hypothesis passes for the most parsimonious auxiliary model, it is strongly rejected when the list of endogenous variables increases, unlike the model tested in Chapter 5. Therefore the hypothesis that subsidies to R&D drive productivity survives this work only weakly. A different and more elaborate model of the R&D channel could perhaps do better, but this must be for future research.

Chapter 8

Welfare Implications of Policy Reform

This chapter presents the aggregate welfare implications of a one-off policy reform in the model for both policy setups, using the model's utility function. This shows the extent to which the growth gains illustrated in the impulse responses (Chapter 2) translate into the consumption and leisure possibilities of the representative agent.

The time t utility function (Eqn. 2.2, Chapter 2) is $u_t = \theta_0(1-\rho_1)^{-1}C_t^{1-\rho_1} + (1-\theta_0)(1-\rho_2)^{-1}x_t^{1-\rho_2}$, where preference shocks to consumption and leisure have been removed. To evaluate the impact of a policy shock on welfare, we calculate the impulse response functions for a one-off 1% reduction in $\tau(1)$. This exercise yields consumption and the real consumer wage over time in terms of log deviation from the base run. Leisure is obtained using the loglinearised intratemporal condition

$$d\ln x_t = \frac{1}{\rho_2}\left(\rho_1 d\ln C_t - d\ln w_t\right) \tag{8.1}$$

To find the rise in utility due to a proportional rise in C_t and x_t, take a Taylor expansion of $u(.)$ around some steady state values of C and x.

$$\begin{aligned} du_t &= \left(\frac{\partial u_t}{\partial C}.C\right) d\ln C_t + \left(\frac{\partial u_t}{\partial x}.x\right) d\ln x_t \\ &= \theta_0 C^{1-\rho_1} d\ln C_t + (1-\theta_0)x^{1-\rho_2} d\ln x_t \end{aligned} \tag{8.2}$$

This utility change is in terms of extra consumption and extra leisure; it is converted into its equivalent in terms of consumption alone by scaling it by the marginal utility of consumption.

$$\begin{aligned} du_t &= \theta_0 C^{1-\rho_1} \overline{d \ln C_t} \\ \overline{d \ln C_t} &= \frac{du_t}{\theta_0 C^{1-\rho_1}} \end{aligned} \tag{8.3}$$

Thus the extra utility resulting in time t after the policy shock, in terms of its equivalent in extra units of consumption, is as follows.

$$\overline{d \ln C_t} = d \ln C_t + \frac{(1-\theta_0) x^{1-\rho_2}}{\theta_0 C^{1-\rho_1}} d \ln x_t \tag{8.4}$$

To find the increase in permanent consumption resulting from the policy shock - call this $\widetilde{d \ln C_t}$ - we require the overall wealth effect of the policy shock to be converted into a per period flow (allow T to approach ∞)

$$\begin{aligned} dU_0 &= \sum_{t=0}^{T} \beta^t \overline{d \ln C_t} = \frac{1}{1-\beta} . \widetilde{d \ln C_t} \\ \widetilde{d \ln C_t} &= (1-\beta) \sum_{t=0}^{T} \beta^t \overline{d \ln C_t} \end{aligned} \tag{8.5}$$

This calculation requires a calibration of the steady state values of C and x in the initial Taylor expansion. Using the intratemporal condition, we know that

$$\frac{\frac{\partial u_t}{\partial x}}{\frac{\partial u_t}{\partial C}} \equiv \frac{(1-\theta_0) x^{-\rho_2}}{\theta_0 C^{-\rho_1}} = w \tag{8.6}$$

so that

$$\frac{\left(\frac{\partial u_t}{\partial x} . x\right)}{\left(\frac{\partial u_t}{\partial C} . C\right)} = \frac{(1-\theta_0) x^{1-\rho_2}}{\theta_0 C^{1-\rho_1}} = w . \frac{x}{C} \tag{8.7}$$

Assume the agent spends half his time in leisure in steady state and the rest in productive activity that earns the real wage, w. That productive time, $(1-x)$, translates into $(1-x)w$ consumption units, implying $x = 0.5$ and $C = w(1-x) = 0.5w$.[1] Substituting these values

[1] i.e. income from net foreign assets is assumed to be zero in steady state, as is the return on capital. Adding these would reduce the impact of leisure in the utility function, but this is anyway quite small (an order of ten

into the equation above shows that $w\frac{x}{C} = 1$. Thus the formula for the increase in permanent income resulting from a policy shock is

$$\begin{aligned} \widetilde{d\ln C_t} &= (1-\beta)\sum_{t=0}^{T}\beta^t\left\{d\ln C_t + \frac{\left(\frac{\partial u_t}{\partial x}.x\right)}{\left(\frac{\partial u_t}{\partial C}.C\right)}d\ln x_t\right\} \\ &= (1-\beta)\sum_{t=0}^{T}\beta^t\left\{d\ln C_t + w\frac{x}{C}d\ln x_t\right\} \\ &= (1-\beta)\sum_{t=0}^{T}\beta^t\left\{d\ln C_t + d\ln x_t\right\} \end{aligned} \tag{8.8}$$

Applying this formula, we find that a one-off 1 percentage point reduction in the barriers to entrepreneurship rate, $\tau(1)$, generates 2.85% extra consumption per period. This is over a simulation horizon of 70 quarters or 17.5 years, as the above formula assumes T becomes very large. For the subsidy model with the set of Wald-minimising coefficients obtained in Chapter 7, a one-off 1 percentage point increase in the subsidy variable raises consumption per period by 3.88% relative to the base run with no shocks.

This simulation exercise demonstrates for both policy-driven models investigated in earlier chapters that a policy-driven growth episode delivers significantly in terms of welfare, as proxied by the utility function. In conjunction with the Directed Wald test results in Chapters 5 and 7, which show that these models pass empirically as the explanatory process for productivity and output, the suggestion is that UK policy over the sample period had substantial effects on both economic growth and welfare.

or more lower than the response of consumption in every period).

Chapter 9

Conclusion

The empirical work carried out in Chapters 5 and 7 shows that government policy has influenced the UK productivity experience. Consistent with the argument of Crafts (2012) and Card and Freeman (2004), the results in Chapter 5 suggest that policy-induced reductions in labour market friction and significant cuts in top rates of personal income tax which began in the early 1980s had a positive and lasting effect on the productivity level, and a reasonably long-lasting effect on the productivity growth rate. An equally weighted combination of corporate tax rate cuts and labour market regulation was also found to have had a positive impact on TFP over the period.

These policies can work through many channels, and it has been theorised elsewhere that the policy incentives ascribed to entrepreneurial activities in Chapters 4 and 5 actually promote innovation through formal R&D activity. The results found in Chapter 5 for labour market regulatory reform may therefore say little about start-up rates or 'entrepreneurship' as it is defined by many, but may work through the R&D channel. We attempted to distinguish these channels by including the top rate of personal income tax in $\tau(1)$, on the basis that personal income tax rates are more directly related to the entrepreneur's decision process than to decisions around R&D.

The subsidy variable investigated in Chapter 7 is focused on government grants to formal R&D expenditure, dominated by large established firms rather than small start-ups generally thought of as entrepreneurial. The results in that chapter show that direct R&D subsidies also played a positive role in stimulating UK productivity growth between 1981 and 2010. This indicates that both direct policy interventions such as subsidies to R&D and indirect 'framework policies' providing an environment in which businesses can operate flexibly (whether through start-up or through formal R&D activity) were important elements in the policy mix underpinning the UK macroeconomic performance in the sample period. Rather than 'barriers to entrepreneurship', the framework policies investigated in Chapter 5 can be more neutrally termed 'barriers to business'.

In Chapters 4 and 6 the existing empirical work on policy determinants of growth was reviewed and it was concluded that this literature is problematic, the most critical drawback being that regressions are usually unidentified and so give no information about the direction of causality or the structural model underlying the reduced form relationship. This has allowed ambiguity to remain about how precisely correlations between dependent and 'independent' variables should be explained in theory.

The empirical work in Chapters 5 and 7 does not suffer from this ambiguity. We have set up an identified DSGE model in which policy reform causes permanent changes in productivity, generating short- to medium-run growth episodes. The simulated features of the bootstrapped model are summarised by an auxiliary model and compared to the features of the UK sample data, and these features are discovered to be close in a formal statistical sense, through the Indirect Inference Wald test. When the hypotheses that chosen policy factors cause growth are embedded in the workhorse DSGE model of Chapter 2, they are not rejected as the data generating processes for UK productivity and output in the last quarter of the 20th century. This is evidence that policy had a causal effect on growth over the period, rather than responding endogenously to the state of the economy or to other forces.

The estimates of the marginal impact of policy reform on short-run productivity growth are large enough in absolute value to ensure that these models are distinguished from exogenous growth models, as variance decompositions have shown, but beyond this we do not emphasize the precise magnitude of the estimates. The focus is instead on their signs. The hypothesis that the net productivity effect of labour market regulation and marginal tax rates on personal income is negative is not rejected empirically for the UK data; equally, the test does not reject the hypothesis that the net productivity effect of direct private sector R&D subsidies (government funding of business R&D as a proportion of total BERD) is positive. Since the Indirect Inference test has strong statistical power to reject a false null, the non-rejections are conclusive evidence of the direction of impact of these policy instruments.

Caution is of course advisable in extrapolating outside the particular samples. Nevertheless, concerns that negative growth effects will result from further cuts in direct funding to private sector R&D appear to be justified based on past experience. The results also suggest that reversing the cuts in the top marginal income tax rate and the small business corporate tax rate could impact economic growth negatively. Likewise, labour market regulation as proxied by centralised collective bargaining and marginal costs of hiring acted as a barrier to growth-enhancing business activities and governments should be careful about reverse the deregulatory reforms enacted in the past; the short- to medium-run growth effects could be non-negligible, with permanent effects on the TFP level.

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Appendix 1

A. The non-stationarity of $\frac{C_t}{Y_t}$

It is assumed that, from the perspective of any period t, the expected ratio of consumption to output is roughly constant for $t+i$, on the basis that the consumption-output ratio is non-stationary and can be approximated as a random walk process without drift. Thus although in balanced growth $\frac{C}{Y}$ will be constant, in the presence of shocks the ratio will move in an unpredictable way (see Meenagh et al. 2007 for further discussion). At any given point in the sample, the model is not in balanced growth, though it can be expected to be tending to it in the distant future if no further shocks are expected. Therefore the assumption here does not rule out the possibility that consumption and output grow at the same rate in the long run equilibrium.

This appears to be a reasonable assumption for the sample of UK data I use. Taking the difference between the natural log series of output and consumption and running an Augmented Dickey Fuller test with a trend and intercept specification leads to a non-rejection of the null of unit root (the p-value is 0.84); a Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test with null hypothesis of stationarity for the same trend specification also offers the same conclusion with a strong rejection of the null (test statistic 1.25, against the critical value of 0.74 for a 1% significance level). Using an unrestricted VECM to generate estimates of $E_t \ln Y_{t+1}$ and $E_t \ln C_{t+1}$, then taking the difference between them and running the same tests gives similar results.

Moreover, the simulated series generated by the bootstrapped model show random walk behaviour.Therefore the model output is consistent with the assumption of a random walk at this stage of the derivation. There may of course be structural breaks in the time series which lead stationarity to be falsely rejected (e.g. Clemente et al. 1999); however, it is not a priori clear where these breaks should be and I abstract from this possibility.

B. Solution method with non-stationary data

The loglinearised rational expectations model is solved using a projection method along the lines of Fair and Taylor (1983).[1] This is most easily explained in general terms; define $E(y_{t+k}|I_{t-1})$ as the value in period $t+k$ of variable y expected at time $t-1$ based on an information set

[1] This discussion follows Pierse (1999).

I_{t-1}. The linearised model can be written so that each equation is normalised on one of the endogenous variables, and represented as follows for $t = 1, ..., T$:

$$y_t = h(y_t, \chi_t, \tilde{Y}_{t-1}, \tilde{X}_t, u_t; \theta)$$

where y_t is a (n x 1) vector of endogenous variables, χ_t is a vector of expected future endogenous variables (expected at time t for $t+1$), $\tilde{Y}_{t-1}$ is a vector of predetermined endogenous variables, $\tilde{X}_t$ is a vector of exogenous variables and u_t is a vector of exogenous shock processes. θ is a vector of calibrated parameters and $h()$ is a n x 1 vector valued function. Suppose some guessed initial time vector for the expectations χ_t^{s-1} , $t = j, ..., j+k$, when $s - 1 = 0$ (s denotes the iteration number). Then, taking the expectations as fixed, solve the system for the endogenous variables at $t = j, ..., j+k$

$$y_t^s = h(y_t^s, \chi_t^{s-1}, \tilde{Y}_{t-1}, \tilde{X}_t, u_t; \theta)$$

using some iterative solution procedure (we use Powell's hybrid algorithm, a modification of Newton's method; see Powell (1970)) to find the time paths over the horizon (1 to k) of the endogenous variables as a function of current and lagged exogenous variables. Then use the solution output for y_t^s, $t = j+1, ..., j+k$, in place of the assumed expectations χ_t^s in the following iteration for $s = 2, ..., S$ or until convergence is achieved according to the chosen stopping criterion. This step ensures that the one period ahead expectations are consistent with the model's own predictions.

An additional constraint on the expectations is that they must satisfy the terminal conditions on the model at $j + k + 1$. These conditions are imposed to ensure that the simulated paths for the endogenous variables converge at some 'terminal' date to a long run level consistent with the model's own long run implications (see Minford et al. 1979). Since the model is not solved using stationarised data and so does not converge to a static steady state, these long run levels will depend on the behaviour of the non-stationary driving variables as they have evolved stochastically over the simulation period (deterministic trend behaviour is removed). The relevant variables in the model are A_t and b_{t-1}^f, both of which are functions of all previous shocks in the model through their unit roots. Setting the terminal conditions on the expectations here involves solving the equilibrium system at some notional future date J, when shocks have ceased, stationary variables have reached their long run constant values and trended variables are growing at constant rates. An additional equilibrium assumption is that the transversality condition holds, so that the level of net foreign assets b_J^f is stable and there is no long run growth in net international debt. Solving for the endogenous variables as a function of the non-stationary variables under these assumptions implies the terminal conditions on their expectations.

Once a dynamic rational expectations solution is found for the window $t = j, ..., j + k$, the algorithm repeats for the window $t = j+1, ..., j+1+k$, using the previously calculated solution values (based on the time j set of shocks) as lagged data in the $j+1$ solution procedure. These steps are repeated for the sample $t = m, ..., T$ (where m is the number of initial conditions). For each simulation window of length k, only the first period of the solution is retained in the final path for the full sample period $t = m, ..., T$; i.e. the final solution is built up from the $T - m$ overlaid simulations of length k.

Appendix 2

This Appendix contains all definitions and sources of data used in the study, as well as a symbol key. The majority of UK data are sourced from the UK Office of National Statistics (ONS); others from International Monetary Fund (IMF), Bank of England (BoE), UK Revenue and Customs (HMRC) and Organisation for Economic Cooperation and Development (OECD). Labour Market Indicators were taken from the Fraser Institute Economic Freedom Project, which sources them from the World Economic Forum's Global Competitiveness Report (GCR) and the World Bank (WB). All data are seasonally adjusted and in constant prices unless specified otherwise.

Symbol	Variable	Definition and Description	Source
Y	Output	Gross Domestic Product; constant prices.	ONS
N	Labour	Ratio of total employment to 16+ working population[1]	ONS
K	Capital Stock	Calculated from investment data (I) using Eqn.2.35	(na)
I	Investment	Gross fixed capital formation + changes in inventories	ONS
C	Consumption	Household final consumption expenditure by households	ONS
A	Total Factor Productivity	Calculated as the Solow Residual in Eqn. 2.28	(na)
G	Government Consumption	General government, final consumption expenditure	ONS
IM	Imports	UK imports of goods and services	ONS
EX	Exports	UK exports of goods and services	ONS
Q	Terms of Trade	Calculated from $\frac{E.P_F}{P}$	(na)
E	Exchange Rate	Inverse of Sterling effective exchange rate	ONS
P_F	Foreign Price Level	Weighted av. of CPI in US (0.6), Germany (0.19) & Japan (0.21)	IMF
P	Domestic General Price Level	Ratio, nominal to real consumption	ONS
b_F	Net Foreign Assets	Ratio of nominal net foreign assets (NFA) to nominal GDP [2]	ONS
w	Consumer Real Wage	Average Earnings Index [3] divided by P_t	ONS
$\widetilde{w}$	Unit cost of labour	Average Earnings Index [3] divided by GDP deflator	ONS
r	Real Interest Rate, Domestic	Nominal interest rate minus one period ahead inflation.	(na)
R	Nominal Interest Rate, Domestic	UK 3 month treasury bill yield	BoE
r_F	Real Interest Rate, Foreign	R_F minus one-period ahead inflation (year-on-year change in P_F)	(na)
R_F	Nominal Interest Rate, Foreign	Weighted av., 3-month discount rates, US, Germany & Japan [4]	IMF
C_F	Foreign Consumption Demand	World exports in goods and services	IMF
$\tau(1)$	Tax & Regulatory Environment	Equally weighted av., LMR and top marginal income tax	HMRC
$\tau(2)$	Tax & Regulatory Environment	Equally weighted av., LMR and corporation tax (SME rate)	HMRC
$\tau(3)$	Labour Market Regulation(LMR)	Equally weighted av., CCB and MCH (interpolated using TUM)	Various
TUM	Trade Union Membership Rate	Trade union membership over working pop (16+).	ONS
CCB	Centralized Collective Bargaining	Survey-based indicator of strength of collective bargaining	GCR
MCH	Marginal Cost of Hiring Index	Doing Business Project Indicator	WB
$SUBS$	Direct subsidy, private R&D	Ratio of government-funded BERD to total BERD [5]	OECD

Table 9.1: Data Description

	$\boldsymbol{\tau}(\mathbf{1})$	$\boldsymbol{\tau}(\mathbf{2})$	$\boldsymbol{\tau}(\mathbf{3})$	**SUBS**
Min.	-0.0695	-0.1208	-0.1701	-0.0516
Max.	0.1162	0.0677	0.0939	0.0669
Std. Dev.	0.0387	0.0437	0.0747	0.0326

Table 9.2: Descriptive Statistics of Linearly Detrended Policy Variables; Constant Removed

Notes to Table 9.1:

[1] Working population is total claimant count plus total workforce jobs.

[2] Nominal NFA is accumulated current account surpluses (£m), taking the Balance of Payments international investment position as a starting point.

[3] AEI for whole economy including bonuses.

[4] Weights as P_F. Germany proxies EU.

[5] BERD is Business Enterprise R&D.

List of Figures

List of Tables