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Tax, Regulation and Economic Growth: A Case Study of the UK

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This paper investigates whether government policy had a causal impact on UK output and productivity growth between 1970 and 2009. An open economy DSGE model of the UK is set up, with productivity growth determined by the tax and regulatory environment in which firms start up and operate. The agent's optimality conditions imply a reduced form linear relationship between policy and short-run productivity growth. Identification is assured for the DSGE model by the rational expectations restrictions; therefore the direction of causality is unambiguously from policy to productivity. The model is estimated and tested by Indirect Inference, a simulation-based method with good power against general misspecification. The results of this study offer robust empirical evidence that temporary changes in policies underpinning the business environment can have long-lasting effects on UK economic growth.

JEL codes: E6, O11, O47, O5, O38

1. Introduction

The question of how growth is generated and whether it can be influenced by policy is still keenly 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, 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 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, 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. 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. It is therefore difficult to draw conclusions on the effectiveness of policy using this approach. 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, writing in 1995, judged 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 (Myles, 2009a, p.16).

A different approach to the macroeconometrics of policy and growth is therefore warranted. 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 "inquire whether the empirical implications of such a model are consistent with the data" (p. 148). This is the approach

[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)

taken in this paper.

Here I investigate whether tax and regulatory policies affected economic growth in recent UK history by acting as a barrier to entrepreneurship, a hypothesis championed by Acs et al. (2009) amongst others. Existing literature points to theoretical ambiguity over the direction of causation in this policy-growth relationship, which complicates the interpretation of many 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 these issues for the UK.

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" (Davis, 2008, p.36). The UK coalition government elected in 2010 strongly endorsed entrepreneurship as an element of its 'Growth Strategy'. Its Plan for Growth (HM Treasury, 2011) consisted 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 were, 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 was 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). There is little sign that the current government will break from this strategy.

This is strong testimony, therefore, to a prevalent belief among UK policymakers that policy drives economic growth, in particular regulatory policy, as this is thought to be a barrier to entrepreneurship.[2] 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 (Figure 1). The UK was an early starter among OECD countries in the deregulation of labour and product markets (see e.g. Figure 2), and this has been credited in part with reversing UK relative economic decline through its stimulating effects on competition and productivity (Crafts, 2012; Card and Freeman, 2004). Here we examine 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, as Baliamoune-Lutz and Garello (2014) note, "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 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.[3] Of course, when respondents are business leaders these perceptions of barriers may be subject to conscious or unconscious bias; such a measure does not by itself have any economic policy implication.

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. 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 suppress growth, or is this empty rhetoric promoted by vested interest groups who would lose from such reforms? This need not imply overt dissembling by lobbyists, since the historical experience may permit this 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 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. The hypothesis is therefore examined within a Dynamic Stochastic General Equilibrium (DSGE) model of

[2]The OECD characterises regulation as a barrier to entrepreneurship. See e.g. OECD (2015), Figure 25, a graph entitled "There is scope to reduce barriers to entrepreneurship" plotting UK Product Market Regulation (PMR) scores against the average 'best' five OECD countries in terms of freedom from PMR.

[3]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 probably due to reductions in corporate tax rates and R&D tax credit increases implemented in intervening years.

the United Kingdom. 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 (1995a,b), as policy is not assumed to determine long-run growth rates in steady state. 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.[4]

Traditionally, calibrated Real Business Cycle (RBC) models have been evaluated by informal comparison of the moments of 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 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 without examining their validity.

In this paper the structural parameters of the growth model are estimated by Indirect Inference. This involves searching across the model's parameter space for the parameters which minimise the test statistic, in a similar approach to Smith (1993) and Canova (1994, 2005), among others. As the literature review makes clear, strong priors do not exist for the calibration of the role of policy in the model, making this estimation procedure a necessary step for testing the hypothesis itself rather than simply a particular numerical set of 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 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 a World Bank index of the mandated cost of hiring). 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. A variance decomposition for the estimated model shows 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, 2015b), so these results 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 paper is structured as follows. A brief overview of the literature on the macroeconomic relationship between tax and regulatory policy, entrepreneurship and productivity is provided in Section 2. Section 3 describes an open economy DSGE model of the UK as a testing vehicle for the policy-driven growth hypothesis. After discussion of key data choices in Section 3.2, Section 4 outlines the Indirect Inference Methodology, while Section 5 presents the empirical work. Section 6 presents the model responses of output and productivity growth to a one-off, temporary 1% policy shock, and Section 7 concludes.

[4] As Friedman noted 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.

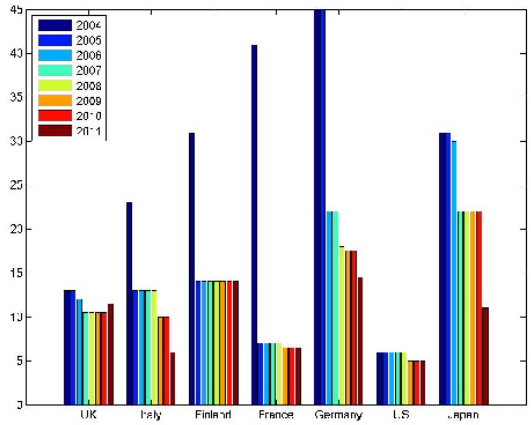

Figure 1. Time Needed to Start a Business, Doing Business Indicators (World Bank)

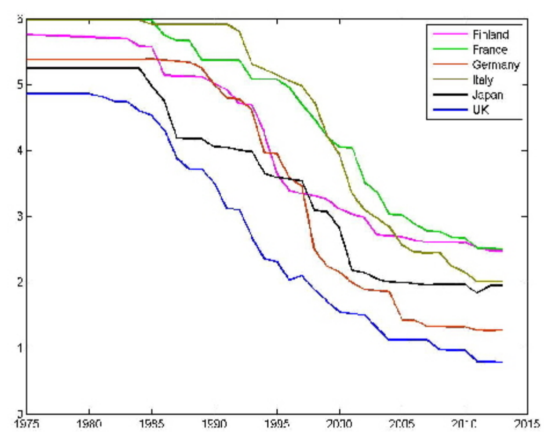

Figure 2. Product Market Regulation, Network Sectors (Energy, Transport and Communications). Source, OECD.

2. Literature Review

A variety of micro-based models exist of the process by which innovation raises productivity. In the New Endogenous Growth Theory, the public good characteristics of knowledge imply spillovers which drive a wedge between private and social returns to innovation (Aghion and Howitt, 1992; Romer, 1990); such models recommend subsidies to research. Lowering barriers to entry may stimulate innovation, but this is theoretically ambiguous (Aghion and Howitt, 2006; Acemoglu, 2008). By construction, different models imply distinct (often conflicting) policies regarding firm entry rates and intellectual property protection. Ultimately, which of these theories applies at the aggregate level is an empirical matter.

Though Aghion and Howitt (1998, p.8) define research activity as broader than formal R&D, when New Endogenous Growth models are taken to the data, innovation is generally proxied by formal R&D expenditure and patent counts (e.g. Jaumotte and Pain, 2005). R&D expenditure is dominated by large established firms, and evidence of this channel therefore overlooks innovation by small and/or new businesses. Acs et al. (2005, 2009) refocus the growth driver on entrepreneurs, assuming that investment in R&D by incumbent firms yields intratemporal spillovers which generate entrepreneurial opportunities; entrepreneurship is decreasing in regulatory and administrative burdens and in government market intervention, termed "barriers to entrepreneurship". These include labour market rigidities, taxes and bureaucratic constraints. In Braunerjhelm et al. (2010), the distribution of scarce resources between R&D and entrepreneurship is as important for growth as purposeful R&D investments (cf. Michelacci, 2003). The message is that "Policy makers would be seriously misguided in focusing exclusively on knowledge creation" (Acs and Sanders, 2013, p. 787), rather than using policies affecting the entrepreneurial choice to raise the effective commercialisation of new knowledge.

Empirical studies on the effect of policy on growth fall roughly into three categories: aggregate growth regressions of GDP growth rates on policy variables directly, plus a range of covariates;[5] calibrated DSGE model-based simulation exercises quantifying the impacts of policy reforms on macroeconomic aggregates; and microeconometric studies examining the effect of policy changes in panels of firm- or industry-level data. The third category, though often more successful at addressing identification issues than the macroeconometric literature, cannot answer our questions about the macro-

[5] For OECD regression studies investigating entrepreneurship as a determinant of growth using various specifications and entrepreneurship proxies, see e.g. Carree et al. (2002), Erken et al. (2008), Acs et al. (2012). For regressions of growth on aggregate measures of regulation directly, see Djankov et al. (2006) and Gorgens et al. (2005). See van Stel et al. (2007) for regressions of nascent and young entrepreneurship on regulation using GEM data.

economic impacts of policy, while simulation exercises take as given that the calibrated mechanism they use is appropriate provided that certain stylized facts are not violated (e.g. Poschke, 2010; Everaert and Schule, 2008; Roeger et al., 2009; Varga and 't Veld, 2011; Gomes et al., 2011; Cacciatore et al., 2012). The quantitative effects of reform depend directly on the calibration and assumed functional forms, so such studies illustrate underlying assumptions about how impacts are generated without testing them. Studies in the first category must overcome significant difficulties if they are to constitute robust evidence of a causal relationship from policy to growth (equally from policy to entrepreneurship, or entrepreneurship to growth). This relates to the absence of specific theoretical restrictions on the parameters of interest.

The impact of regulation on economic growth is theoretically ambiguous. According to public interest theory (Pigou, 1938), market failures arise from information asymmetries, monopoly power or externalities, which hamper growth if government does not correct them using regulation. However, in public choice theory regulation is a tool of socially malign government for extracting rents (e.g. Stigler, 1971), implying a negative relationship between regulation and growth. A third theory of regulation is 'government failure' whereby regulation, though benign in intention, negatively impacts market outcomes due to flawed design or enforcement.[6] Distinguishing between these theories in the data is impossible since government disposition and competence is unobserved. Macro-level regressions of growth on regulation in a cross-section of countries may admit multiple interpretations. For instance, public interest theory might predict that regulation successfully neutralises market failure, enhancing growth relative to the no regulation case (positive causation from policy intervention to growth). However, Djankov et al. (2002) argue public interest theory implies negative correlation between regulation and growth; a thriving economy is less prone to market failure and hence has no need of regulatory intervention (causation from higher growth to lower regulation). Clearly a straightforward regression of growth on regulation will not distinguish between different causal hypotheses, and may suffer from endogeneity bias. The latter is addressed in some studies by instrumenting regulation in the regression, often with legal origin and/or dictatorship indicators (Djankov et al., 2002, 2006; Klapper et al., 2006). This correction is only as robust as the instruments, which often are weak, lack time series variation or are potentially endogenous themselves (Basannini et al., 2009, pp. 379-380).

Above we noted that product market regulation and other barriers to entry have different theoretical impacts on equilibrium innovation according to the model setup; contrast Aghion et al. (2013) with Acemoglu and Cao (2010). For the estimated impact of OECD product market deregulation on investment and productivity growth, see Nicoletti and Scarpetta (2003), Bourlès et al. (2013) and Alesina et al. (2005).[7]

Again, the growth effect of labour market regulation (LMR) is *a priori* ambiguous. Employment protection legislation (EPL) may increase investment in skills due to increased job tenure, leading to higher productivity growth (Damiani and Pompei 2010; Belot et al. 2007). Alternatively, 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. The empirical literature does not offer a firm consensus on the direction of impact of LMR on economic growth or on employment; contrast Bassanini et al. (2009), DeFreitas and Marshall (1998), Di Tella and MacCulloch (2005) and Lazear (1990) with Nickell and Layard (1999) and Koeniger (2005).

A multitude of theoretical predictions exists likewise for the tax-growth and tax- entrepreneurship relations, again reflected in a lack of empirical consensus. Many cross-country growth regressions include the overall share of tax revenue in GDP as an explanatory variable, i.e. the national average tax rate. While some theory suggests that certain taxes distort important investment margins, reducing growth significantly (King and Rebelo, 1990; Jones et al., 1993), the overall effect of tax revenue on growth is ambiguous. Endogenous growth models with public goods as productive inputs imply that 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 (Barro, 1990). 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. Of course, negative growth effects arise in theory not from average but from marginal tax rates, which are not the same in OECD economies due to progressivity in the schedule. However, due to the inherent difficulties in measuring effective marginal rates the average tax rate is still widely included as a regressor.[8]

Tax is a highly politicised area and rates certainly respond to political pressures, which respond in turn to

[6] Equally, regulation may lower growth if it is designed with other non-economic objectives in mind, such a human rights protection, wealth redistribution or defence. Thus government failure from a growth perspective might not be a failure when assessed on different criteria. Though we do not lose sight of this point, government failure is defined here in terms of the growth objective.

[7] See Scarpetta et al. (2002) for firm-level estimation of PMR and LMR effects on new firm entry rates; also Klapper et al. (2006).

[8] Some attempt to calculate an 'effective' marginal tax rate at the economy level (Koester and Kormendi, 1989; Easterly and Rebelo, 1993), but whether these capture cross-country differences in tax design consistently is controversial.

the state of the economy. Therefore regressions with tax instruments on the right hand side and growth on the left are vulnerable to criticisms of endogeneity. Government expenditure responds to country-level political preferences (Slemrod, 1995), and the demand for public goods increases with income (Wagner's Law) implying reverse causality in the average tax–growth relationship. These regressions lack structural underpinnings, depriving their estimates of a clear interpretation; while they may provide evidence of association, little can be concluded as to causality. See Myles (2009a,b) for comprehensive surveys of empirical work on the tax-growth relationship using aggregate and disaggregate data, respectively.

The impact of tax on entrepreneurship is equally indeterminate in theory; high marginal tax rates may discourage the risk neutral entrepreneur, but may insure the risk averse entrepreneur against failure (Gentry and Hubbard, 2000). For regression studies of the impact of marginal tax rates on entrepreneurship see the overview in Baliamoune-Lutz and Garello (2014, p. 169); the sign and magnitude of the estimated effects differs broadly both across countries and within countries for different studies. For aggregate panel regressions of entry rates on corporate tax rates see Djankov et al. (2010) and Da Rin et al. (2011).

To summarise, macro-level regressions suffer from a variety of methodological limitations and are rarely sufficiently identified, making the interpretation of estimated relationships difficult; simulation exercises around the macroeconomic impacts of tax and regulatory policy reforms are usually conducted in calibrated structural models which are rarely tested in a formal sense; microeconometric studies do not address the macroeconomic policy impacts we are interested in here. To discover the aggregate relationship between UK tax and regulatory policy and economic growth, we must test theories in an identified setup where the direction of causation is unambiguous.

Here we examine the hypothesis that innovative business activity is discouraged by the prospect of labour market frictions encountered during firm operation, and by the top marginal tax rate on personal income. This causal mechanism – from an increase in regulation and marginal tax rates 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) our tax and regulatory policy index 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 Section 5.

3. Model and Data

3.1. The Model

The open economy Real Business Cycle model is adapted from Meenagh et al. (2010), with the addition of an endogenous growth process based on Meenagh et al. (2007). 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 calibrated UK model has performed well in similar tests (Meenagh et al., 2010), the introduction of the policy variable should test whether this policy hypothesis alone has caused the rejection.

The model is given in Appendix A. It 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. The home country here is calibrated to the UK economy and the foreign country represents the rest of the world, its size allowing foreign prices and consumption demand to be treated as exogenous. International markets are cleared by the real exchange rate.

The home country features a representative consumer, a representative profit-maximising firm operating in a perfectly competitive final goods market, and a government which spends on the consumption good and raises funds through taxation and bond issue. The consumer chooses to consume, hold savings instruments, and divide time between activities (leisure, productive labour and an innovative activity), to maximise utility subject to 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 (Appendix A, eq. 51) with systematic dependence on the level of time spent in an innovative activity, z_t, itself a choice variable of the consumer (cf. Lucas, 1990). This activity is subject to a proportional cost due to government policy. In this paper, z_t is conceived of as entrepreneurship. A sizable literature is devoted to finding a precise and workable definition of this activity and the plurality of definitions is 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.[9] Here the entrepreneurial growth channel includes both the creative responder/destructor identified by Schumpeter (1947, 1942) and the arbitrageur emphasized by Kirzner (1973). While Schumpeter's entrepre-

[9]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.

neur 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. 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, since entrepreneurial incentives are otherwise undermined.

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 agent operating in a perfect competition general equilibrium model with full information, following Friedman's 'as if' approach (Friedman, 1953).[10] Non-rival technology - leading to costless spillovers - and fixed innovating costs have led many to discard perfect competition as a viable framework for examining innovation. However, Boldrin and Levine (2008, 2002) argue against costless spillovers, since ideas are embodied in a person or good and their transmission is costly. Returns to technological progress generated by the entrepreneur may accrue formally to fixed factors of production, rather than appearing as supernormal profits.[11]

The model in Appendix A assumes perfect competition on this basis, but note that we are not wedded to this micro-structure. This model provides a framework in which to test the hypothesis of interest; namely whether a causal relationship from policy 'barriers to 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.[12] Additional micro-level complexity may add little, and risks obscuring the interpretation of the indirect inference test results reported below. If a reduced form relationship from policy to growth is found, it can be a matter for future work to examine what sort of micro-based process could be driving it.

The model assumes a marginal 'tax' or 'penalty' rate on z_t, reflecting the extent to which z_t is penalized by the policy environment overall i.e. by regulatory barriers which raise both entry costs and operational costs for businesses, and profit taxes which reduce the appropriability of entrepreneurial returns. Data for the penalty rate, τ'_t, 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 Appendix A, eq. 56). In this way entrepreneurship itself is bypassed and no data on entrepreneurs is required for the model's solution and simulation. The onus is 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.

The model is derived in full in Appendix A. It is solved using a projection method along the lines of Fair and Taylor (1983), which ensures that the one period ahead expectations are consistent with the model's own predictions. Additionally, the expectations must satisfy terminal conditions on the model at the end of the simulation window. These conditions are imposed to ensure that the simulated paths for the endogenous variables converge at the 'terminal' date to a long run level consistent with the model's own long run implications (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 depend on the behaviour of the non-stationary driving variables as they have evolved stochastically over the simulation period (deterministic trend behaviour is removed).

3.1.1. The Log-Linearised System

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. $\hat{b}^f_t$, which is the ratio of net foreign assets to output). For notational clarity, $\ln(C^d_t)^*$ and $\ln C^f_t$ have been replaced with $\ln EX_t$ and $\ln IM_t$, respectively. Constants are suppressed into the error terms. 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

[10] Acs et al. (2013) take a similar position. "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." (p.)

[11] "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" (Boldrin and Levine, 2002, p.18)

[12] Contrast this with the 'homeomorphic' modelling endorsed by many behavioural economists (Wakker, 2010, p.3), which also requires the model's assumptions to fit the data to some level of 'realism'.

v_t, see equations 47 and 58).[13] 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 variable on which the relevant equation has been normalised.

$$
\begin{aligned}
r_t &= \rho_1 \left(E_t \ln C_{t+1} - \ln C_t \right) + e_{r,t} && (1)\\
\ln Y_t &= \alpha \ln N_t + (1-\alpha) \ln K_t + \ln A_t && (2)\\
\ln N_t &= \ln Y_t - \tilde{w}_t + e_{n,t} && (3)\\
\ln K_t &= \zeta_1 \ln K_{t-1} + \zeta_2 \ln K_{t+1} && (4)\\
&\quad + \zeta_3 \ln Y_t - \zeta_4 r_t + e_{k,t} \\
\ln C_t &= \frac{\bar{Y}}{\bar{C}} \ln Y_t - \frac{\bar{EX}}{\bar{C}} \ln EX_t + \\
&\quad \frac{\bar{IM}}{\bar{C}} \ln IM_t - \frac{\bar{K}}{\bar{C}} \ln K_t + \\
&\quad (1-\delta-\gamma_k) \frac{\bar{K}}{\bar{C}} \ln K_{t-1} - \frac{\bar{G}}{\bar{C}} \ln G_t && (5)\\
\ln \tilde{w}_t &= \rho_2 \ln N_t + \rho_1 \ln C_t + \\
&\quad \left[\frac{1-\omega}{\omega} \right]^{\sigma} \ln Q_t + \rho_2 2 c_1 \tau_t' + e_{wh,t} && (6)\\
\ln w_t &= \ln \tilde{w}_t - \left[\frac{1-\omega}{\omega} \right]^{\sigma} \ln Q_t + e_{w,t} && (7)\\
\ln EX_t &= \ln C_t^* + \sigma^F \frac{1}{\omega} \ln Q_t + e_{X,t} && (8)\\
\ln IM_t &= \ln C_t - \sigma \ln Q_t + e_{M,t} && (9)\\
\ln Q_t &= E_t \ln Q_{t+1} + r_t^f - r_t && (10)\\
\Delta \hat{b}_{t+1}^f &= (r_t^f - g) \hat{b}_t^f + \\
&\quad \left(\frac{1}{1+g} \right) \left(\begin{array}{c} \frac{EX}{\bar{Y}} \ln EX_t - \frac{EX}{\bar{Y}} \frac{1}{\omega} \ln Q_t \\ - \frac{IM}{\bar{Y}} \ln IM_t \end{array} \right) && (11)\\
\ln A_t &= \ln A_{t-1} + b_1 \tau_{t-1}' + e_{A,t} && (12)\\
\ln C_t^* &= \rho_{C^*} \ln C_{t-1}^* + \eta_{C^*,t} && (13)\\
\ln G_t &= \rho_G \ln G_{t-1} + \eta_{G,t} && (14)\\
r_t^f &= \rho_{rf} r_{t-1}^f + \eta_{rf,t} && (15)\\
\tau_t' &= \rho_\tau \tau_{t-1}' + \eta_{\tau,t} && (16)
\end{aligned}
$$

3.1.2. Stochastic processes

There are eleven stochastic processes in the model, all either straightforwardly stationary or trend stationary, taking the following AR(1) form:

$$e_{i,t} = a_i + b_i t + \rho_i e_{i,t-1} + \eta_{i,t} \quad (17)$$

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 AR(1) coefficients ρ_i are estimated using the residuals extracted from the structural model, given the calibration. To find 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. When $a_i \neq 0$ and $b_i \neq 0$, the linearly detrended residual $\hat{e}_i$ is used, where

$$
\begin{aligned}
\hat{e}_{i,t} &= \rho_i \hat{e}_{i,t-1} + \eta_{i,t} && (18)\\
\hat{e}_{i,t} &= e_{i,t} - \hat{a}_i - \hat{b}_i t && (19)
\end{aligned}
$$

The innovations $\eta_{i,t}$ are approximated by the fitted residuals from estimation of equation 18, $\hat{\eta}_{i,t}$. These are then used to bootstrap the model. The bootstrapping methodology is discussed in Section 4.

Shocks are to r_t, $\ln N_t$, $\ln K_t$, $\ln \tilde{w}_t$, $\ln EX_t$ and $\ln IM_t$. r_t^f, $\ln C_t^*$, government spending and τ_t' are stochastic exogenous variables. The Solow residual $\ln A_t$ is modelled as a unit root process with drift driven by a stationary AR(1) shock and by exogenous variable τ_t', based on equation 56 (Appendix A).

$$
\begin{aligned}
\ln A_t &= d + \ln A_{t-1} + b_1 \tau_{t-1} + e_{A,t} && (20)\\
e_{A,t} &= \rho_A e_{A,t-1} + \eta_{A,t} && (21)
\end{aligned}
$$

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 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. 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 this paper. A balanced growth path of the model is assumed to exist in that, at some notional future date with no shocks, 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. We aim 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 z_t. 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.

[13]Where equations are not straightforwardly linear in logs, they are linearised around sample mean values, denoted by overbar. The capital 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 eq. 37, allowing the approximation: $\ln p_t^d - \ln Q_t = -(\frac{1-\omega}{\omega} + 1) \ln Q_t = -\frac{1}{\omega} \ln Q_t$. If these approximations are not good enough this will show up empirically.

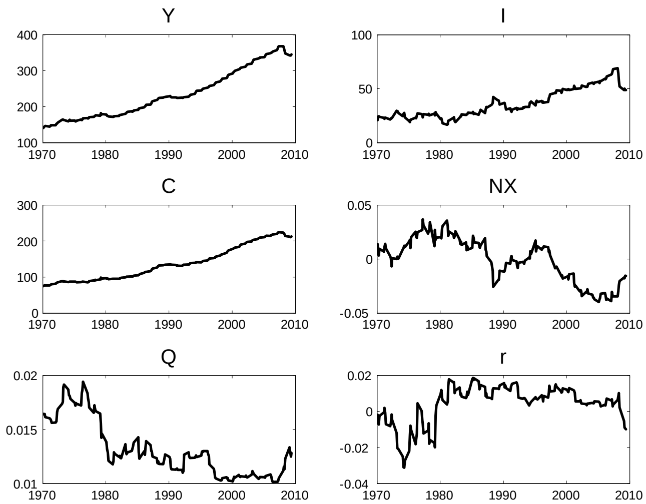

Figure 3. Key UK data, quarterly. Real GDP in £bn (Y), Investment (I), Consumption (C), Net Exports over GDP (NX), Relative Price of Imports to Exports (Q), and Domestic Real Interest Rate (r)

3.2. Data

Data descriptions are given in Appendix B with symbol key. Raw data on key variables are plotted in Figure 3. While many have acknowledged the difficulties presented by filtering using Hodrick-Prescott (HP) or Band Pass procedures, it is still dominant practice in the RBC literature.[14] When the focus is on stochastic growth behaviour, this treatment is inappropriate. Fluctuations around potential correspond in this model to short-run or 'transitional' growth episodes in the data; those are of crucial interest here, but filters may not extract them accurately. Transition periods following a shock are often long, and there may occasionally be large shocks. In both cases the HP filter distorts the estimates of underlying trends; where we would want to analyse the model's adjustment to the policy shock, the HP filter may interpret it as a change in underlying potential and remove it. In general, it can alter the time series properties of the data, inducing spurious autocorrelation and variability in individual series and spurious comovement between series (Canova, 2014). It is therefore inappropriate to use HP-filtered data in applied work on the short- and medium-run growth impacts of policy. Therefore raw, unfiltered data is used for the endogenous variables when solving, testing and estimating the model. Only exogenous variables are detrended where they are modelled as stationary.

[14]See discussion in Canova, 2014.

3.2.1. Measuring Policy

According to the model, the policy variable is a systematic driver of the productivity level via the activities (z_t) which it either stimulates or discourages. 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 results in Section 5. Indeed, it determines which theory is tested there. 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, by reducing the expected return to those activities, or (equivalently) raising 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 Section 2 some theoretical motivation was given for the choice of certain policy drivers of entrepreneurship and productivity growth, and the ambiguity over the predicted direction of impact was noted. Whether (or which of) these theories hold in the data is an empirical matter. Here we focus on policies which might target productivity via our conception of entrepreneurship; I limit the scope to tax and regulatory policies. The loose definition of entrepreneurship adopted here following the Wennekers and Thurik (1999) synthesis embraces diverse activities for which the policy-related incentives are numerous, interacting in complex ways at the micro level. We require 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.

Recognising the distinction between productive and unproductive entrepreneurship (Baumol, 1990), the chosen index should capture only those aspects of the policy environment which lead to innovative business activity. Excessive regulatory or tax burdens can lead to unproductive entrepreneurship as individuals divert energy to avoidance or evasion, or to lobbying for their removal; removing them should then 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.

Since z_t is productive entrepreneurship in the model, τ_t' will ideally exclude any policies that incentivise the unproductive type. For instance τ_t' should not include 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.[15] 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.

3.2.2. Data for the Policy Variable

A less aggregated measure of τ' is preferred, to minimize 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. Two components are selected from the labour market sub-section of the Economic Freedom (EF) 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 is 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)."[16] The Fraser Institute converts these scores onto a [0,10] interval. The MCH index is constructed from World Bank Doing Business data, and reflects "the cost of all social security and payroll taxes and the cost of other mandated benefits 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.[17] Thus labour market flexibility increases with both indices in their raw form. These [0,10] scores are scaled to a [0,1] interval before being interpolated as follows.

	CCB	MCH
MCH	0.797	1.000
TUM (inv)	0.899	0.764

Table 1
Correlations: Labour Market Indicators CCB and MCH, and inverted Trade Union Membership rate (TUM inv).

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. This series is inverted and used to interpolate both the CCB and MCH series via the Denton proportionate variant adjustment method (Denton, 1971).[18] It seems reasonable to use the unionisation rate to interpolate CCB and MCH 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 may well be correlated with a strong worker voice, usually represented by unions.[19] The correlations in the data bear this out (Table 1).

The resulting quarterly series for CCB and MCH incorporate information from the unionisation rate.[20] These interpolated series are inverted so as to represent

[15]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.

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

[17]"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).

[18]The series is inverted by subtracting it from one, so that a value closer to one now implies a lower trade unionisation rate.

[19]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).

[20]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.

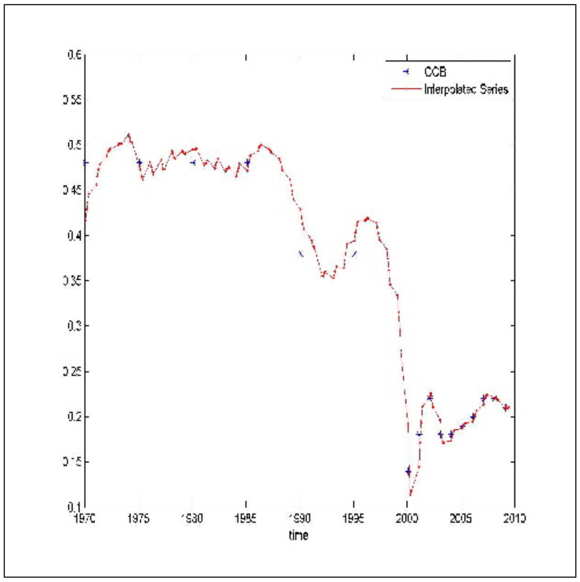

Figure 4. Inverted Fraser Institute Centralized Collective Bargaining (CCB) Score; Original Points and Interpolated Series.

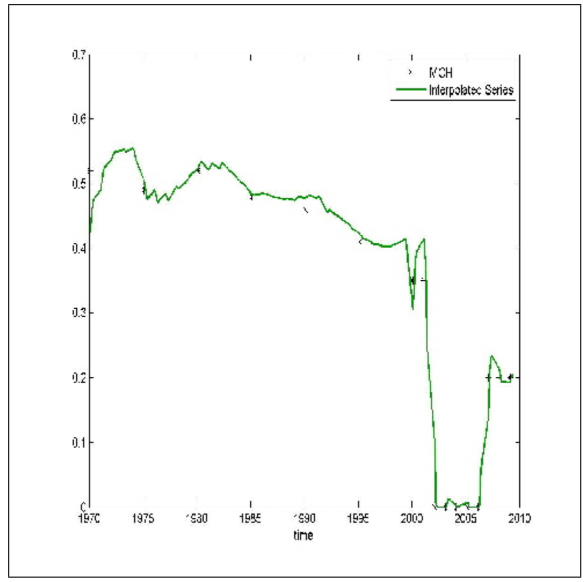

Figure 5. Inverted Fraser Institute Marginal Cost of Hiring Score; Original Points and Interpolated Series.

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

Table 2
Correlations: OECD Product Market Regulation Indicator (Network Industries), Fraser Institute Indicators (CCB and MCH), Trade Union Membership

a penalty rate, where a higher value indicates a more hostile business environment.[21] They are plotted below in Figures 4 and 5 against the scatter of low frequency data points (scaled to [0,1] and inverted). 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 (Figure 6), labelled the ‘Labour Market Regulation’ indicator (LMR).[22] Other types of regulation are not incorporated into τ'_t in this study, since measures spanning the sample period are largely unavailable. However, it is interesting to note the high positive correlation between the Fraser Institute CCB and MCH measures and the OECD indicator of Product Market Regulation (PMR, Table 2).[23] 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 viewed as a serious barrier by UK businesses and these were 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 significant 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 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 entrepreneurs for the period 1970-2009, I use

[21] Again, the inversion involves subtracting the existing values from one.

[22] A fuller measure of regulatory burden in labour markets would 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.

[23] Correlations are between the raw EF measures and the inverted OECD measure – for all measures a higher value indicates less regulation.

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.[24] 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. Other empirical work is consistent with this approach.[25]

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 its inclusion 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 size distribution in way that has nothing to do with productivity growth. This occurred in the UK after the 2002 Budget when the corporation tax starting rate on profits up to £10,000 was reduced to zero (Crawford and Freedman, 2010). For this reason the corporation tax rate is not included in the main τ_t' index, $\tau(1)$. However, an alternative policy variable $\tau(2)$ constructed from the labour market indicator and the corporation tax rate (in place of the top marginal income tax rate) is used in robustness tests to check the estimated 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 with missing quarterly values set equal to 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 Figure 6. The top marginal income tax rate and the labour market regulation index are combined into a single measure by a simple average with equal weights (Figure 7). Series components are highly correlated (Table 3). The main index $\tau(1)$ is plotted in Figure 7.

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

[24] 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.
[25] Note e.g. 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.

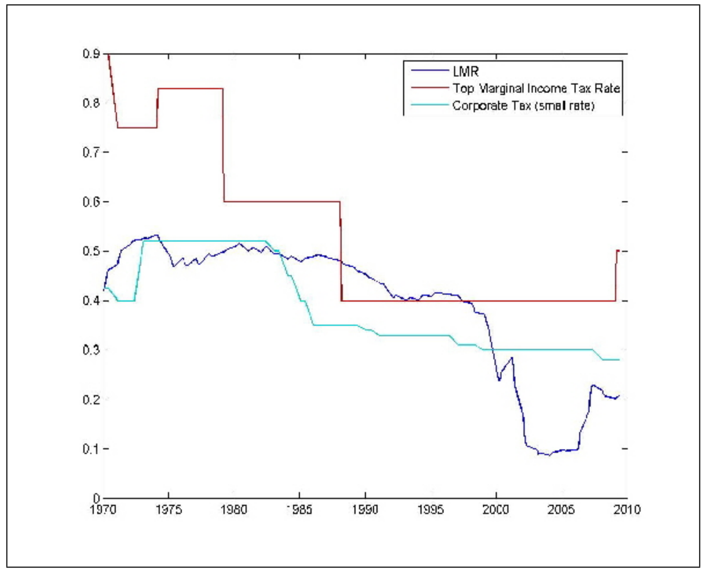

Figure 6. Top Marginal Income Tax Rate, Labour Market Regulation Indicator, and Corporation Tax (SME rate)

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

Table 3
Correlation Coefficients for Tax and Regulatory Components of Composite Index. Correlations are with inverted, interpolated CCB and MCH series

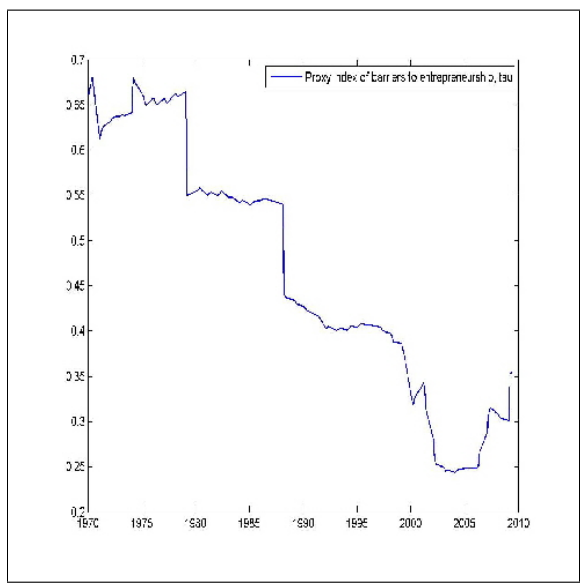

Figure 7. Evenly weighted combination of top marginal income tax rates and the labour market regulation indicator, $\tau(1)$

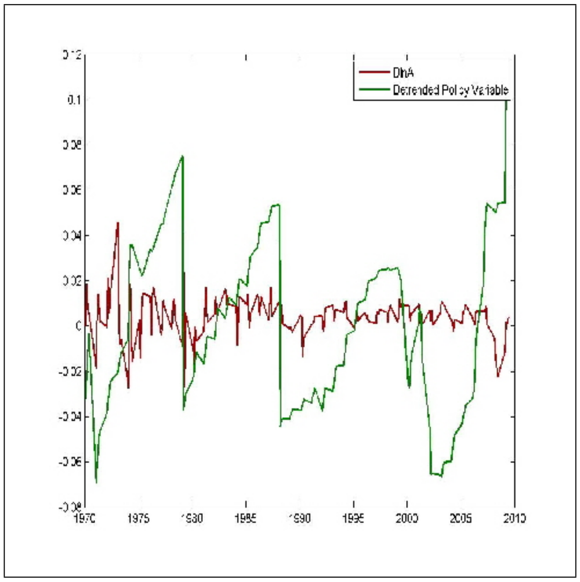

Figure 8. Linearly Detrended Policy Variable $\tau(1)$ and $D\ln A$

a random walk with drift or a trend stationary process, perhaps with a structural break around 2002. Results of KPSS and ADF tests are inconclusive on this question; given this ambiguity and the low power of these tests, it is reasonable to treat the series as trend stationary.[26]

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 Section 3.1.1). The detrended $\tau(1)$ series is plotted against the changes in the Solow residual (in logs) for the original sample data in Figure 8. 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 Section 4; 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).

4. Methodology

Indirect inference adopts an auxiliary model as a descriptor of the joint features of the data (both observed and simulated). Basing 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 (Le et al. 2010, 2011). 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'.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. We ask 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.

Drawing repeatedly from assumed asymptotic distributions to obtain new sets of shocks is not justified when these distributions are unknown. 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.[27] The bootstrap involves drawing randomly with replacement from the innovations and using these pseudo-random shocks to generate simulated datasets conditional on the model. The small-sample properties of the bootstrap are checked by numerical methods in Le et al. (2011) and found reliable.[28]

The full indirect inference testing procedure is formally outlined elsewhere; see e.g. Le et al. 2011, and Le et al. 2014 for the application to non-stationary data. Here the steps are given in brief. Using calibrated parameter set (θ), J bootstrap simulations are generated from the DSGE model.[29] Having added back the effects of deterministic trends removed from shocks, the auxiliary model is estimated for all J pseudo-samples. 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 $WS(\theta)$

[26]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.

[27]The structural model equations - in conjunction with the observed data and a particular coefficient set - imply certain 'structural' residuals in order to hold with equality. Where expectations enter on the right hand side of structural equations they are are estimated using a LIML procedure (McCallum, 1976; Wickens, 1982). These are in turn modelled as autoregressive processes, depending on i.i.d. innovations extracted from the equations given in Section 3.

[28]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.

[29]Here $J = 1000$.

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. Thus the Wald statistic utilises the first and second moments and cross-moments of the distribution of the auxiliary model coefficients that describe the data generated by the model.[30] The test statistic, $WS^*(\theta)$, is

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

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. We then see where this test statistic falls within the model-generated distribution. Inference proceeds by comparing the percentile of the Wald distribution at which the test statistic falls with the chosen size of the test; for a 5% significance level, a percentile above 95% signifies rejection. Alternatively we can present the same information as a p-value[31] or a t-statistic, obtained from the square root of the Wald, also known as the Mahalanobis distance.[32] 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 used here with a direct likelihood-based test, using a Monte Carlo experimental strategy; they find that the power of the Indirect test as applied 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 test in empirical work. In this paper, Indirect Inference methodology is applied for the first time to a semi-endogenous growth model of the UK, using non-stationary data.

The rational expectations DSGE modelling approach used here has the advantage of being an identified test of a particular causal explanation of growth. Thus the DSGE model being tested has a distinct reduced form that 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 impose overidentifying restrictions on its reduced form representation, approximated here by the auxiliary model[33]. 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 Indirect Inference test is the basis for the Indirect Inference estimation carried out in Section 5. The estimation procedure involves searching over the parameter space 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).[34]

In Section 5, a 'simulated annealing' algorithm is employed to perform the indirect inference Wald test for 1,000 points inside the parameter space, logging the relevant test statistics for each. I have searched within 30% bounds of an initial calibration based for the most part on Meenagh et al. (2010), for selected parameters; these are generally preference-related parameters, as well as the policy-growth parameter, for which no strong priors exist. The initial calibration ultimately loses its importance since if the starting value is far wrong, the search results should tend strongly to one of the bounds. The bounds can then be shifted appropriately. The same auxiliary model is used throughout the estimation procedure.

4.1. Choice of Auxiliary Model

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. An auxiliary

[30] The high power of this method relative to Likelihood based tests is due in part to the use of the restricted covariance matrix in constructing the Wald statistic, as opposed to the unrestricted COV matrix.

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

[32] Since the Wald is a chi-squared, the square root is asymptotically a normal variable.

[33] 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 here 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.

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

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. In Appendix C 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 (1).

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, which 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. Some misspecification in the model is acknowledged 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 against which 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 22 serves as the auxiliary model used in the empirical work, being a parsimonious description of some key features of the model.[35]

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

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. The errors are also tested for stationarity. 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 assumptions of the model, being a non-stationary variable on which the non-stationary endogenous variables depend. 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 it is left 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 in Appendix C, 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 that VARX is tested for the stationarity of its residuals.[36] OLS is a biased estimator of the auxiliary model

[35] 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.

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

$\tau(1)$	Equally weighted average: LMR and top marginal tax rate on personal income
$\tau(2)$	Equally weighted average: LMR and corporate tax rate (SME rate)
$\tau(3)$	LMR alone

Table 4
Key to Policy Variables

α	Labour share in output	0.7
β	Quarterly discount factor	0.97
δ	Quarterly depreciation rate	0.0125
g	Long run quarterly growth rate, Y and K	0.005

Table 5
Fixed Parameters

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).

5. Empirical Work

In this section the model in Appendix A is set up to test the hypothesis that tax and regulatory policies 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.

Section 5.1 presents the results of the indirect inference estimation for this model. Results are presented for three different measures of τ' described earlier (Table 4).

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, showing 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.

Given the model's size, there is considerable theoretical freedom over what values the parameters could take. Certain aspects of the calibration are held fixed throughout (Tables 5 and 6). The discount factor β is calibrated at 0.97 following Meenagh et al. (2010). On the production side the share of labour in output, α, is calibrated at 0.7, consistent with UK estimates reported by Gollin (2002). Quarterly capital depreciation is set at 0.0125 following Meenagh et al. (2010). The linearised balance of payments condition is calibrated from UK post war data averages (1955 – 2011) with $\frac{M}{Y}=0.2135$, $\frac{X}{Y}=0.208$, and long-run quarterly output growth $g=0.005$.[37] In the market clearing constraint, $\frac{Y}{C}$ and $\frac{G}{C}$ are calibrated to UK post-war averages: $\frac{Y}{C}=1.732$, $\frac{G}{C}=0.44$. To ensure consistency 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 capital is assumed to be $\gamma_k=0.005$. We assume $\frac{K}{Y}=3$ so that $\frac{K}{C}=3.\frac{Y}{C}=5.196$. Ultimately whether this is a good enough approximation is an empirical issue. These parameters are fixed during the estimation process, while all other model parameters are allowed to vary provided that the logic of the model is preserved.[38]

5.1. Indirect Inference Estimation Results

The Wald-minimising set of coefficients discovered for this model with $\tau(1)$ as the policy variable driving productivity is given in Table 7. The test statistic gives a Wald percentile of 72, well within the non-rejection

[37] $\hat{b}^f_{t+1}\equiv\frac{b^f_{t+1}}{Y_{t+1}}$, so net foreign assets is expressed as a ratio to GDP and the whole equation is scaled by the sample average of output.

[38] e.g. while ζ (a fixed adjustment cost parameter) and d (the firm's discount factor) in the coefficients of the capital demand equation (eq. 4) allow some empirical flexibility, $\zeta_3=1-\zeta_1-\zeta_2$ is an important constraint to ensure consistency with the long run. In steady state with no shocks or adjustment costs, capital and output grow at the same rate, or the capital-output ratio is not stable; since by detrending the shocks we remove the deterministic growth path, we require $\ln K=\ln Y$ in the long run.

$\frac{K}{C}$	$\frac{Y}{C}$	$\frac{IM}{C}$	$\frac{EX}{C}$
0.196	1.732	0.369	0.361
$\frac{G}{C}$	$\frac{EX}{Y}$	$\frac{IM}{Y}$	$\frac{Y}{K}$
0.442	0.208	0.213	0.333

Table 6
Long Run Ratios, Fixed Throughout

ρ_1	θ_0	c_1	ρ_2
0.9712	0.5267	−0.0568	1.5198
ω	σ	σ_F	ω_F
0.5431	0.7676	0.8522	0.8819
ζ_1	ζ_2	ζ_3	ζ_4
0.6359	0.3349	0.0240	0.2365
b_1		$Wald\%$	
−0.1209		72.23	

Table 7
Wald Minimising Coefficient Values for Tau(1) Model

area of the bootstrap distribution. Impulse response functions for this calibration have been checked and are logically sound for each shock. The implied AR(1) coefficients for the exogenous stochastic processes are reported in Table 8.The estimates of the import and export elasticities with respect to a change in relative price sum to 2.337, satisfying the Marshall-Lerner condition. The estimates are also consistent with US estimates obtained by Feenstra et al. (2014), "in the neighbourhood of unity regardless of sector" (p.34), and also with UK estimates from empirical studies such as Hooper et al. (2000). The long run constraint on the capital equation that $\zeta_3 = 1 - \zeta_1 - \zeta_2$ is also approximately satisfied. The estimated capital equation coefficients imply a strong pull of past capital on the current value (0.636), indicating high adjustment costs. The lower estimate of the coefficient on the forward expectation of capital, ζ_2, at 0.3349 implies a fairly high discount rate for the firm, far higher the consumer's rate. 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 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. There-

e_r	e_A	e_N	e_K	e_w	e_X
0.8713	0.237	0.898	0.990	0.959	0.959
e_M	τ	C^*	r^F	G	
0.951	0.968	0.918	0.967	0.935	

Table 8
AR(1) coefficients for structural shocks given estimated parameters

fore some non-stationarity is introduced into the system even by the stationary shocks, and the non-stationarity induced by the shocks to τ' 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 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 some insight into the historical data from 1970-2009 given the non-rejection of the model. The variance decomposition is obtained by bootstrapping the model and calculating the variance in each simulated endogenous variable for each shock separately, as reported in Table 9. 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 18% 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 provides a test of its macroeconomic performance in more dimensions, which is of course a more stringent test. These results are reported in Appendix D. 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. However, the emphasis remains on auxiliary model (1). That the DSGE model performs reasonably well in other dimensions is encouraging, but the purpose of this study has been to test its implications for output and TFP, with particular focus on the causal role of tax and regulatory policy.[39]

[39]The results found for tax and regulatory reform may work through a formal R&D channel as well as through 'entrepreneurship' (see e.g. Jaumotte and Pain, 2005). We tried to distinguish these channels by including the top rate of personal income tax in $\tau(1)$, on the basis that this tax rate is more directly related to the entrepreneur's decision than to formal R&D decisions. However, the precise activities through which the policy $\tau(1)$ translates into productivity remain open in this study. These policies can be more neutrally termed 'barriers to business'.

	$\mathbf{r}$	$\mathbf{Y}$	$\mathbf{N}$	$\mathbf{K}$	$\mathbf{C}$	$\mathbf{w}$	$\widetilde{\mathbf{w}}$	$\mathbf{X}$	$\mathbf{M}$	$\mathbf{Q}$	$\mathbf{b}^F$	$\mathbf{d(A)}$
$\mathbf{e(r)}$	0.1833	0.0016	0.0080	0.0033	0.0370	0.0471	0.0005	0.0118	0.0800	0.0114	0.0396	0
$\mathbf{e(A)}$	0.0453	0.1320	0.1056	0.0244	0.1018	0.0611	0.1339	0.1342	0.0880	0.1298	0.0087	0.8146
$\mathbf{e(N)}$	0.0150	0.0012	0.0111	0.0002	0.0012	0.0251	0.0086	0.0005	0.00001	0.0005	0.0008	0
$\mathbf{e(K)}$	0.1748	0.1515	0.1308	0.8323	0.1067	0.0568	0.1316	0.1091	0.0574	0.1055	0.0208	0
$\mathbf{e}(\widetilde{\mathbf{w}})$	0.1314	0.0070	0.0786	0.00003	0.0106	0.0054	0.0006	0.0023	0.000004	0.0052	0.0004	0
$\mathbf{e(X)}$	0.0174	0.0044	0.0511	0.00002	0.0704	0.2564	0.0004	0.0452	0.2395	0.0653	0.5242	0
$\mathbf{e(M)}$	0.0034	0.0016	0.0180	0.00002	0.0588	0.1743	0.0001	0.0434	0.1364	0.0419	0.1642	0
$\boldsymbol{\tau}'$	0.2876	0.6997	0.5865	0.1370	0.5193	0.1709	0.7238	0.6174	0.1559	0.5970	0.1008	0.1854
$\mathbf{C}_F$	0.0014	0.0006	0.0070	0.00001	0.0336	0.0836	0.0001	0.0114	0.0945	0.0195	0.0560	0
$\mathbf{r}_F$	0.1377	0.0003	0.0027	0.0027	0.0616	0.1192	0.0005	0.0247	0.1483	0.0239	0.0843	0
$\mathbf{G}$	0.0027	0.00004	0.0006	0.00001	0.0001	0.0001	0.00001	0.0001	0.00001	0.00005	0.0002	0

Table 9
Variance Decomposition for Tau(1) Model Given Estimated Coefficients

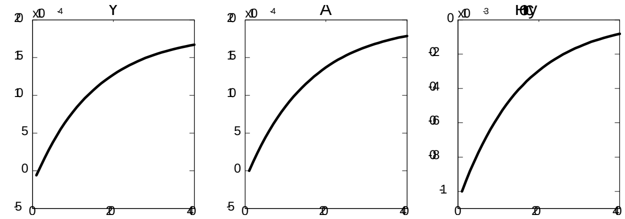

Figure 9. Responses of output and TFP to a one-off, temporary cut in the 'barriers to business' proxy of 1 percentage point, given estimated structural coefficients.

5.1.1. Robustness

The Wald-minimising set of coefficients discovered for the $\tau(1)$ series were also tested on the baseline auxiliary model using $\tau(2)$, the equally weighted simple average of the LMR indicator with the tax rate on corporate profits (small business rate). When the Wald-minimising calibration in Table 7 is used with the $\tau(2)$ series are larger test statistic is obtained than for $\tau(1)$. The Wald percentile is roughly 85, 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 Wald-minimising coefficient set in Table 7 the model driven by $\tau(3)$ is also not rejected at the 5% significance level, yielding a Wald percentile of 94.41.

These robustness checks show that the non-rejection of the model for these coefficients is not overly sensitive to the weighting and 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. However, the inclusion of the top marginal income tax rate with its large step changes yields a substantially lower Wald percentile for the model and this policy component seems to have had important effects.[40]

A full set of impulse response functions (IRFs) was obtained for every shock in the model and for every policy series. Though not presented here in the interests of brevity, these impulse response functions show that the model generates standard RBC behaviour.

6. Growth Episode After A Policy Reform

Impulse response functions for a one-off 1 percentage point reduction in $\tau(1)$ illustrate the growth episode generated by the temporary policy reform. The first 40 quarters are plotted in Figure 9 for output and total factor productivity, alongside the policy reform. Note that although the policy shock is temporary, it affects the level of productivity permanently and shocks the productivity growth rate above its deterministic rate for a lengthy period; the one-off shock generates a productivity growth episode lasting over 40 quarters (Figure 9).[41] The 1 percentage point $\tau(1)$ shock is gradually reversed over time, taking ten years to die away; on average this implies that the penalty is 0.5 percentage points lower for 10 years. The log level of output is 2 percentage points higher than its no-shock level after 17.5 years. This translates to an average higher growth rate of 0.11 percentage points per annum. The growth multiplier effect of an average 0.5 percentage point $\tau(1)$ reduction over ten years is therefore in the region of 0.2 for two decades. Relating this to the UK data, Figure 8 shows two large downward shocks around trend, the first at 1979, the second at 1988; these correspond to the 1979 budget and the 1988 budget, both of which contained sharp personal income tax rates cuts in the top band (from 0.83 to 0.6, and from 0.6 to 0.4 respectively). This model would explain the observed reversal of UK economic decline between 1980 and the 2000s (Crafts, 2012) as the result of such policy shocks.

In conjunction with the Directed Wald test results in Section 5.1, which show the estimated model passes empirically as the explanatory process for productivity, output and a range of other macroeconomic variables, the suggestion is that UK policy over the sample period had substantial effects on economic growth and welfare.[42]

7. Conclusion

In Section 2, 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 often unidentified, and so unclear about the direction of causality and the structural model underlying the reduced form relation-

[40] Robustness was also carried out around the interpolation technique of $\tau(1)$. The conclusions are unchanged when the Denton method is applied in levels rather than differences for the labour market indicators. Where components are interpolated to quarterly frequency, robustness checks around the interpolation technique show the conclusions are similarly unaffected (constant match interpolation was checked against quadratic interpolation).

[41] 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. At first, 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, the real 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 also triggers a real business cycle upswing, not illustrated.

[42] Using the model's utility function (eq. 24) to calculate the aggregate welfare implications of the one-off temporary reform confirms that these growth gains are not achieved at the expense of the representative agent's welfare, as proxied by the assumed function of consumption and leisure. However, this welfare function is basic and I do not emphasise the welfare implications of the reform.

ship. This has allowed ambiguity to remain about how precisely correlations between dependent and 'independent' variables should be explained in theory. The empirical work in Section 5.2 does not suffer from this ambiguity. An identified model was set up in which policy reform causes 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 an indirect inference Wald test. This is evidence that certain policy factors had a causal effect on growth and productivity between 1970 and 2009; specifically, temporary movements in tax and regulatory policy around long run trend drive short-run productivity growth via marginal incentive effects on innovative business activity.

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 empirical results show that these proxies for 'barriers to entrepreneurship' had a negative impact on UK total factor productivity growth, consistent with the argument of Crafts (2012), Card and Freeman (2004) and Acs et al. (2009). The non-rejection of the estimated model is robust to adjustments around the policy variable. Moreover, the model performs well when a variety of endogenous variables are added to the auxiliary VARX(1). 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 percentage points per quarter. Note that this is not a statement about long-run growth rates, which are outside the scope of this study.

The results indicate that policies factors providing an environment in which businesses can operate flexibly and innovatively were important to the UK macroeconomic performance in 1970-2009. The estimates of the marginal impact of policy reform on short-run productivity growth are large enough in absolute value to ensure that the model is distinguished from an exogenous growth model, as the variance decomposition shows. Since this indirect inference Wald test has been shown elsewhere to have strong statistical power (Le et al., 2015b), the non-rejections of the tests reported in Table D are conclusive evidence of the direction of impact of these policy instruments at the macroeconomic level.

Caution is of course advisable in extrapolating outside the 1970-2009 sample period. Nevertheless, these results suggest that reversing the cuts in the top marginal income tax rate and the small business corporate tax rate would impact economic growth negatively. Likewise, the study indicates that labour market regulation as proxied by centralised collective bargaining and mandated costs of hiring acted as a barrier to growth-enhancing business activities in the past and the reversal of past deregulatory reforms could have sizeable short- to medium-run growth effects, with permanent effects on the TFP level. Any reforms that are carried out can be expected to create significant variability in macroeconomic variables, as indicated by the variance decomposition. It would be wise to incorporate such dynamic macroeconomic impacts into a full cost-benefit analysis for proposed reform in these areas.

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A. Model Derivation

A.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:

$$U = \max E_0[\sum_{t=0}^{\infty} \beta^t u(C_t, x_t)] \tag{23}$$

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

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

(24)

$\rho_1, \rho_2 > 0$ 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):

$$N_t + x_t + z_t = 1 \tag{25}$$

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). The agent receives income at t in the form of labour wages, maturing bonds, and dividends (d_t) on shares purchased last period, holding additional purchasing power from the current sales value of shareholdings, $q_t S^p_{t-1}$. The agent is also liable for a taxbill T_t, defined further below. The choice of z_t is left aside for now. 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, where the price P_t of the consumption bundle is numeraire.

$$\begin{aligned} C_t + b_{t+1} + Q_t b^f_{t+1} + q_t S^p_t + \tilde{b}_{t+1} = w_t N_t - T_t \\ + b_t(1+r_{t-1}) + Q_t b^f_t (1+r^f_{t-1}) + \\ (q_t + d_t) S^p_{t-1} + (1+\hat{r}_{t-1})\tilde{b}_t \end{aligned} \tag{26}$$

Q_t is a unit free measure of the price of the foreign consumption good relative to the general domestic price, 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.[43] $\hat{E}_t \equiv \hat{E} \equiv 1$ throughout, so 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 utility with respect to C_t, x_t, b_{t+1}, b^f_{t+1}, $\tilde{b}_{t+1}$ and S^p_t, subject to time and budget constraints. The first order conditions yield the Euler equation (27), the intratemporal condition (28),[44] real uncovered interest parity (29), and the share price formula (30). 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.

$$\frac{1}{(1+r_t)}\gamma_t C_t^{-\rho_1} = \beta E_t[\gamma_{t+1} C_{t+1}^{-\rho_1}] \tag{27}$$

$$\frac{U_x}{U_c}|_{U=0} = \frac{(1-\theta_0)\xi_t x_t^{-\rho_2}}{\theta_0 \gamma_t C_t^{-\rho 1}} = w_t \tag{28}$$

$$(1+r_t) = E_t \frac{Q_{t+1}}{Q_t}(1+r^f_t) \tag{29}$$

$$q_t = \frac{q_{t+1} + d_{t+1}}{(1+r_t)} = \sum_{i=1}^{\infty} \frac{d_{t+i}}{\prod_{j=0}^{i-1}(1+r_{t+j})} \tag{30}$$

The condition in equation 30 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 returns on all assets (S^p_t, b_{t+1}, $\tilde{b}_{t+1}$ and b^f_{t+1}) are equal at the margin.

In this two-country model 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 a single-industry version of the Armington model (Armington, 1969; cf. Feenstra et al. 2014), featuring a multi-level utility structure.[45] 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.[46] The level of consumption C_t chosen above must satisfy the expenditure constraint on consumption,

$$C_t = p^d_t C^d_t + Q_t C^f_t \tag{31}$$

where p^d_t and Q_t are domestic and foreign prices relative to the general price level, P_t . Given the identity in equation 31, the consumer chooses C^d_t and C^f_t to maximise $\tilde{C}_t$ according to the following CES aggregator utility function (equation 32), subject to the constraint that $\tilde{C}_t \leqslant C_t$.

$$\tilde{C}_t = [\omega(C^d_t)^{-\rho} + (1-\omega)\varsigma_t(C^f_t)^{-\rho}]^{-\frac{1}{\rho}} \tag{32}$$

[43] The foreign bond b^f_{t+1} is a real bond, in that it costs the same amount as a unit of the foreign consumption basket (C^*_t), i.e. P^*_t, where P^*_t is the foreign CPI. In domestic currency, this is $P^*_t\hat{E}_t$. Assuming that $P^*_t \simeq P^f_t$ (i.e. exported goods from the home country have little impact on 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.

[44] 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.

[45] 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.

[46] Having discovered the optimal choice of C_t for the level-one utility maximisation, we 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^d_t, and the foreign variety, C^f_t.

At the point of the maximum the constraint is binding so that consumption-equivalent utility, $\tilde{C}_t$, is equal to the amount spent on consumption goods, C_t (the variable appearing in the budget constraint of the main consumer problem). Domestic consumers have some fixed preference bias towards the domestic good, reflected in the parameter $0 < \omega < 1$. 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 $\sigma = \frac{1}{1+\rho}$. First order conditions imply the relative demand for the imported good (33) and the relative demand for the domestic consumption good (34).

$$\frac{C_t^f}{C_t} = \left(\frac{(1-\omega)\varsigma_t}{Q_t}\right)^\sigma \tag{33}$$

$$\frac{C_t^d}{C_t} = \left(\frac{\omega}{p_t^d}\right)^\sigma \tag{34}$$

Given equation 33, the symmetric equation for foreign demand for domestic goods (exports) relative to general foreign consumption is

$$(C_t^d)^* = C_t^* \left(\left(1-\omega^F\right)\varsigma_t^*\right)^{\sigma^F} (Q_t^*)^{-\sigma^F} \tag{35}$$

where * signifies a foreign variable and ω^F and σ^F are respectively the foreign home bias and 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, and $\ln Q_t^* \simeq \ln p_t^d - \ln Q_t$.[47] An expression for p_t^d follows from the maximised equation 32 where $\tilde{C}_t = C_t$ combined with the relative demand functions 33 and 34:

$$1 = \omega^\sigma (p_t^d)^{\rho\sigma} + [(1-\omega)\varsigma_t]^\sigma Q_t^{\rho\sigma} \tag{36}$$

A first order Taylor expansion around a point where $p^d \simeq Q \simeq \varsigma \simeq 1$, with $\sigma = 1$, yields the loglinear approximation:

$$\ln p_t^d = \hat{k} - \frac{1-\omega}{\omega}\frac{1}{\rho}\ln\varsigma_t - \frac{1-\omega}{\omega}\ln Q_t \tag{37}$$

where $\hat{k}$ is a constant of integration. Using this relationship, the export demand equation is

$$\ln(C_t^d)^* = \check{c} + \ln C_t^* + \sigma^F \frac{1}{\omega}\ln Q_t + \varepsilon_{ex,t} \tag{38}$$

where $\check{c}$ collects 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 and capital account deficit sum to zero.

$$\Delta b_{t+1}^f = r_t^f b_t^f + \frac{p_t^d EX_t}{Q_t} - IM_t \tag{39}$$

[47]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.

A.2. Firm Problem

The firm produces the final good using constant returns to scale technology, with diminishing marginal products to labour and capital inputs. Production is described by a Cobb Douglas function (A_t is total factor productivity):

$$Y_t = A_t K_t^{1-\alpha} N_t^\alpha \tag{40}$$

The firm also faces convex adjustment costs to capital, which take a quadratic form. The firm undertakes capital investment in this model, raising funds to purchase new capital by issuing debt ($\tilde{b}_{t+1}$) at t, the cost of which is $\hat{r}_t$ payable 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 $\tilde{a}_t$.[48] The firm's profit function is:

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

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. From the consumer's first order conditions it follows 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:

$$\pi_t = Y_t - K_t(r_t + \delta + \kappa_t) - \frac{1}{2}\zeta(\Delta K_t)^2 - (\tilde{w}_t + \chi_t)N_t \tag{41}$$

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

The firm maximises expected profits subject to these constraints, through its choices of K_t and N_t, taking prices r_t and $\tilde{w}_t$ as given. Assume free entry into the sector and a large number of firms operating under perfect competition. The Lagrangian for the problem is L_0:

$$\mathcal{L}_0 = E_0 \sum_{t=0}^{\infty} d^t E_t \left\{ \begin{array}{c} Y_t - K_t(r_t + \delta + \kappa_t) - \\ \frac{1}{2}\zeta(\Delta K_t)^2 - (\tilde{w}_t + \chi_t)N_t \end{array} \right\} \tag{42}$$

ζ is a multiplicative constant affecting adjustment costs, while d is the firm's discount factor.[49] From the first order condition for K_t, the marginal product of capital (net of adjustment costs and δ) is equal to its unit price, plus a cost shock.

$$(1-\alpha)\frac{Y_t}{K_t} - \delta - \zeta\Delta K_t + d\zeta E_t(\Delta K_{t+1}) = r_t + \kappa_t \tag{43}$$

This implies a non-linear difference equation in capital.

$$K_t = \frac{1}{1+d}K_{t-1} + \frac{d}{1+d}E_t K_{t+1} + \frac{(1-\alpha)}{\zeta(1+d)}\frac{Y_t}{K_t} - \frac{1}{\zeta(1+d)}(r_t + \delta) - \frac{1}{\zeta(1+d)}\kappa_t \tag{44}$$

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

[49]These parameters allow some empirical flexibility when the model is calibrated.

Given capital demand from equation 44, the firm's investment, I_t, follows via the linear capital accumulation identity:

$$K_t = I_t + (1-\delta)K_{t-1} \tag{45}$$

The f.o.c. with respect to labour equates the marginal product of labour to the real unit cost of labour ($\tilde{w}_t$) plus the stochastic cost shock term χ_t. This gives the firm's demand for labour condition.

$$N_t = \alpha . \frac{Y_t}{\tilde{w}_t + \chi_t} \tag{46}$$

Note that differentiated goods at the international level introduce a wedge between $\tilde{w}_t$ and the consumer real wage, w_t. The real cost to the domestic firm is the nominal wage W_t relative to the unit value of the domestic good, P_t^d, while the consumer real wage is relative to the general price level, which combines domestic and imported goods. $p_t^d \equiv \frac{P_t^d}{P_t}$ so the wedge is $p_t^d = \frac{w_t}{\tilde{w}_t}$ implying, via 37, the relationship in equation 47.

$$\ln w_t = \hat{k} + \ln \tilde{w}_t - \frac{1-\omega}{\omega} \ln Q_t - \frac{1-\omega}{\omega} \frac{1}{\rho} \ln \varsigma_t \tag{47}$$

A.3. Government

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

$$G_t + b_t(1 + r_{t-1}) = T_t + b_{t+1} \tag{48}$$

T_t is revenue collected from consumers. As well as raising tax revenues the government borrows, issuing bonds maturing one period ahead. Each period government raises tax revenues to cover spending on transfers and 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 and the government is fully solvent in every period. Revenue T_t is made up as follows.

$$T_t = \tau_t z_t + \Phi_t \tag{49}$$

τ_t is a proportional rate on time spent in innovative activity z_t. Assuming that all policy costs on z_t are genuine external social costs redistributed to the consumer via a reduction in the lumpsum levy Φ_t, tax revenue collected by government is equal to that taxbill paid by consumers.[50] Φ_t, a lumpsum tax capturing the revenue effects of all other tax instruments, responds to changes in $\tau_t z_t$ to keep tax revenue neutral in the government budget constraint. Government spending is modeled as an exogenous trend stationary AR(1) process.

$$\ln G_t = g_o + g_1 t + \rho_g \ln G_{t-1} + \eta_{g,t} \tag{50}$$

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

[50]Potentially only a proportion $0 < \psi < 1$ of the penalty on z_t enters the government budget as revenue, the rest being deadweight loss that reduces the payoff to innovation without benefiting the consumer in other ways. Here ψ is assumed to be 1.

A.4. Endogenous Growth

Assume productivity growth depends linearly on time spent in an innovative activity, z_t.

$$\frac{A_{t+1}}{A_t} = a_0 + a_1 z_t + u_t \tag{51}$$

where $a_1 > 0$. z_t is a systematic channel through which policy incentives, τ_t, can drive growth.[51] The characterisation of z_t depends on the data used for its tax, and on certain elements of calibration. By manipulation of its first order condition, z_t can be bypassed altogether in the model so that productivity growth depends on the tax variable τ_t' alone (eq. 56). This section derives the linear relationship between productivity growth and τ_t' driving the model's dynamic behaviour in simulations. The model is conceptually similar to Lucas (1988, 1990) where growth is endogenous to the agent's decision to spend time in human capital accumulation.[52] The endogenous growth process used here is from Meenagh et al. (2007), adapted for a decentralised framework.

The consumer maximises utility (eq. 23 and 24) with respect to z_t, subject to budget and time constraints and the taxbill (eq. 25 ,26 and 49), taking all other choices as given.[53] We make the consumer's shareholdings equivalent to a single share in every period: $S_{t-1}^p = S_t^p = \bar{S} = 1$.[54] The value per share given in equation 30 is then the value of the firm as a whole. Dividend income d_t is everything leftover from revenue after labour and capital input costs are paid, i.e. profits.

The rational agent expects z_t to raise his own consumption possibilities through his role as the firm's sole shareholder, knowing equation 51 (a marginal change in z_t results in permanently higher productivity from period $t+1$). This higher productivity is fully excludable and donated to the atomistic firm he owns; higher productivity is expected to raise household income via firm profits paid out as dividends. The agent assumes his choice will not affect economy-wide aggregates; all prices are taken as parametric. The productivity increase is not expected to increase the consumer real wage

[51]All other factors that might systematically affect growth - e.g. human capital or R&D investment - are in the error term.

[52]In Lucas' model human capital, once accumulated, raises labour efficiency in production and hence earnings, though in the short term the return to labour (for a given level of human capital) is foregone to increase 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.

[53]Given the time constraint, a full set of optimality conditions 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. The intratemporal condition in 28 gives the margin between x_t and N_t; here I focus on the decision margin between z_t and N_t, so 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.

[54]Each period the consumer demands S_t^p and the price per share must be such that the number of shares supplied (normalised at one) are held by the consumer. The assumption allows the substitution to be made in the budget constraint that $q_t S_t^p - (q_t + d_t)S_{t-1}^p = -d_t$.

here, though it does so in general equilibrium.

The first order condition is given in equation 52:

$$\frac{dL}{dz_t} = 0 = -\beta^t \lambda_t w_t - \beta^t \lambda_t \tau_t + E_t \sum_{i=1}^{\infty} \beta^{t+i} \lambda_{t+i} . \frac{d\ d_{t+i}}{dz_t} \tag{52}$$

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 (lower in period t due to reduced employment time), innovation penalties (higher at t in proportion to the increase in z_t), and expected dividend income.[55] With substitution from 51, the condition can be rearranged as follows:

$$\begin{aligned} \beta^t \gamma_t C_t^{-\rho_1} w_t &= \frac{a_1}{a_0 + a_1 z_t + u_t} . E_t \sum_{i=1}^{\infty} \{ \beta^{t+i} \gamma_{t+i} C_{t+i}^{-\rho_1} Y_{t+i} \} \\ & -\beta^t \lambda_t \tau_t \end{aligned} \tag{53}$$

On the left hand side is the return on the marginal unit of N_t, 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 time t costs attached to innovative activities which are captured by τ_t.[56] τ_t therefore stands for the extent to which the returns resulting from z_t (via its impact on future productivity) are not appropriated by the innovator responsible for generating them. Substituting again from 51 for z_t yields

$$\frac{A_{t+1}}{A_t} = a_1 . \frac{E_t \sum_{i=1}^{\infty} \beta^i \gamma_{t+i} C_{t+i}^{-\rho_1} Y_{t+i}}{\gamma_t C_t^{-\rho_1} (w_t + \tau_t)} \tag{54}$$

The preference shock to consumption, γ_t, is modelled as $\gamma_t = \rho_\gamma \gamma_{t-1} + \eta_{\gamma,t}$, $\rho_\gamma < 1$. Setting $\rho_1 \simeq 1$, we approximate $\frac{C_t}{Y_t}$ as a random walk, so $E_t \frac{Y_{t+i}}{C_{t+i}} = \frac{Y_t}{C_t}$ for all $i > 0$.[57] The expression becomes

$$\frac{A_{t+1}}{A_t} = a_1 . \frac{\frac{\beta \rho_\gamma}{1 - \beta \rho_\gamma} . \frac{Y_t}{C_t}}{\frac{w_t}{C_t} (1 + \tau_t')} \tag{55}$$

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 55 around a point where $\frac{Y_t}{w_t} = \frac{Y}{w}$ and $\tau_t' = \tau'$ gives a linear relationship exists between $\frac{A_{t+1}}{A_t}$ and τ_t' of the form

$$d \ln A_{t+1} = b_0 + b_1 \tau_t' + \varepsilon_{A,t} \tag{56}$$

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.[58] Note that this relationship came out of the first order condition for z_t. The household chooses z_t taking all other sources of productivity growth as exogenous. Equation 56 drives the behaviour of the model in simulations. To reiterate, in this model we abstract from the public goods features of productivity, so spillover effects are absent and the market structure is perfect competition. The entrepreneur donates the productivity output of z_t excludibly to the firm he owns as sole shareholder.

Substituting into 55 using 51 reveals a relationship between z_t and τ_t'. Define $\frac{\partial z_t}{\partial \tau_t'} \equiv c_1$, and assume this is constant. This parameter enters the simulation explicitly in the producer real wage equation, derived as follows from the intratemporal condition (eq. 28) which governs labour supply choices. Taking the total derivative of the time endowment in 25 and assuming that $\bar{N} \approx \bar{x} \approx \frac{1}{2}$ in some initial steady state with approximately no z activity implies

$$\frac{dx_t}{\bar{x}} = d \ln x_t \approx -d \ln N_t - \frac{dz_t}{\bar{N}} = -d \ln N_t - 2 dz_t \tag{57a}$$

Substituting into the loglinearised intratemporal condition for $\ln w_t$ from 47 and using 57a, we obtain

$$\begin{aligned} \ln \tilde{w}_t &= \rho_2 \ln N_t + \rho_1 \ln C_t + \left[\frac{1 - \omega}{\omega} \right]^\sigma \ln Q_t + \\ & \rho_2 2 c_1 \tau_t' + e_{w,t} \end{aligned} \tag{58}$$

where $e_{w,t} = const - \ln \gamma_t + \ln \xi_t + \frac{1}{\rho} \left[\frac{1-\omega}{\omega} \right]^\sigma \ln \varsigma_t$. i.e. the unit labour cost shock combines preference shocks to consumption, leisure and import demand. Since τ_t' is a penalty on innovative activities, $c_1 < 0$ and hence $\frac{d \ln \tilde{w}_t}{d \tau_t'} < 0$ and $\frac{d \ln N_t}{d \tau_t'} > 0$, since eq. 58 is simply the labour supply condition rearranged. The worker's response to a higher penalty rate on z_t is to raise time spent in ordinary employment.[59]

[55] For $i \geq 1$, $\frac{dA_{t+i}}{dz_t} = \frac{dA_{t+i}}{dA_{t+i-1}} . \frac{dA_{t+i-1}}{dA_{t+i-2}} ... \frac{dA_{t+1}}{dz_t} = A_{t+i} \frac{A_t}{A_{t+1}} a_1$, so $\frac{dd_{t+i}}{dz_t} = \frac{Y_{t+i}}{A_{t+i}} A_{t+i} \frac{A_t}{A_{t+1}} a_1$. It may be objected that dz_t will enhance output directly through its effect on productivity (holding inputs fixed), and will also induce the firm to hire more inputs in order to exploit their higher marginal products. I assume the effect of dz_t on the future dividend ($d_{t+i} = \pi_{t+i}$) is simply its direct effect on TFP, since input demand effects are second order. The expected change in the dividend stream is based on forecasts for choice variables (set on other f.o.c.'s) that are assumed 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.

[56] 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.

[57] Although in balanced growth $\frac{C}{Y}$ is constant, in the presence of shocks the ratio will move in an unpredictable way (see Meenagh et al. 2007 for discussion).

[58] $\frac{Y_t}{w_t}$ is treated as part of the error term.

[59] Substituting into equation (55) from (51) and rearranging for z_t, then taking the derivative with respect to τ_t', we find $c_1 = -\frac{\frac{\beta \rho_\gamma}{1 - \beta \rho_\gamma} \frac{Y_t}{C_t^{\rho_1}}}{\frac{w_t}{C_t^{\rho_1}} (1 + \tau_t')^2}$; we could potentially calibrate c_1 from this, taking appropriate values for righthand side variables. However there is flexibility around what values might be considered appropriate.

A.5. 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.

$$Y_t = C_t + I_t + G_t + EX_t - IM_t \tag{59}$$

All asset markets also clear.

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.

$$r_T^f b_T^f = -\left(\frac{p_T^d.EX_T}{Q_T} - IM_T\right) \tag{60}$$

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 $t \rightarrow \infty$, 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).

B. Data

This Appendix contains all definitions and sources of data used in the study, as well as a symbol key. Most 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 are 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 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.45	(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. 40	(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

Table 10
Data Description

C. Auxiliary Model

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

$$A(L)y_t = BE_t y_{t+1} + C(L)x_t + D(L)e_t \quad (61)$$

$$\Delta x_t = a(L)\Delta x_{t-1} + d + b(L)z_{t-1} + c(L)\epsilon_t \quad (62)$$

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

$$y_t = G(L)y_{t-1} + H(L)x_t + f + M(L)e_t + N(L)\epsilon_t \quad (63)$$

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)[60]:

$$\begin{aligned} y_t &= [I - G(1)]^{-1}[H(1)x_t + f] \quad (64)\\ &= \Pi x_t + g \quad (65) \end{aligned}$$

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

$$y_t - (\Pi x_t + g) = \eta_t \quad (66)$$

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.

$$\begin{aligned} \bar{y}_t &= \Pi \bar{x}_t + g \quad (67)\\ \bar{x}_t &= [1 - a(1)]^{-1}[dt + c(1)\xi_t] \quad (68)\\ \xi_t &= \Sigma_{s=0}^{t-1}\varepsilon_{t-s} \quad (69) \end{aligned}$$

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

$$\begin{aligned} \Delta y_t &= -[I - G(1)](y_{t-1} - \Pi x_{t-1}) + P(L)\Delta y_{t-1}\\ &\quad + Q(L)\Delta x_t + f + \omega_t \quad (70)\\ \omega_t &= M(L)e_t + N(L)\varepsilon_t \quad (71) \end{aligned}$$

[60]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.

which can be approximated as

$$\Delta y_t = -K[y_{t-1} - \Pi x_{t-1}] + R(L)\Delta y_{t-1} + S(L)\Delta x_t + h + \zeta_t \quad (72)$$

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

$$\begin{aligned} \Delta y_t = &-K[(y_{t-1} - \bar{y}_{t-1}) - \Pi(x_{t-1} - \bar{x}_{t-1})] +\\ &R(L)\Delta y_{t-1} + S(L)\Delta x_t + m + \zeta_t \quad (73) \end{aligned}$$

considering ζ_t to be i.i.d. with zero mean. Rewriting equation 72 as a levels VARX(1) we get

$$y_t = [I - K]y_{t-1} + K\Pi x_{t-1} + n + \phi t + q_t \quad (74)$$

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.

D. Indirect Inference Test Results: Alternative Auxiliary Models

Auxiliary model	**(1)**	**(2)**
Endogenous	Y, A	Y, A, r
Wald percentile	72.23	82.37
Auxiliary model	**(3)**	**(4)**
Endogenous	Y, A, Q	Y, A, K
Wald percentile	90.16	92.93
Auxiliary model	**(5)**	**(6)**
Endogenous	Y, A, N	Y, A, C
Wald percentile	94.41	95.05
Auxiliary model	**(7)**	**(8)**
Endogenous	Y, A, r, Q	Y, A, N, C
Wald percentile	89.47	94.04
Auxiliary model	**(9)**	**(10)**
Endogenous	Y, A, r, K	Y, A, r, N
Wald percentile	94.80	94.92
Auxiliary model	**(11)**	**(12)**
Endogenous	Y, A, Q, N	Y, A, K, C
Wald percentile	95.12	94.26

Notes on results. In all auxiliary model specifications, exogenous variables included in the test were τ_{t-1} and b^f_{t-1}. Deterministic trend and constant terms also enter the model specification, but these parameters capture long run growth and are therefore excluded from the test when the focus is on growth episodes around trend.