Cardiff Economics Working Papers

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Working Paper No. E2015/16

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

Lucy Minford

November 2015, updated June 2016

ISSN 1749–6101

Cardiff Business School
Aberconway Building
Colum Drive
Cardiff CF10 3EU
United Kingdom
t: +44 (0)29 2087 4000
f: +44 (0)29 2087 4419
business.cardiff.ac.uk

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

Lucy Minford
Cardiff Business School
E-mail: MinfordL@cf.ac.uk

Version: May 2016

This paper investigates the causal relationship between government policy and UK output and productivity growth between 1970 and 2009. In an open economy DSGE model of the UK, productivity growth is determined by the tax and regulatory environment in which firms operate. Identification is assured for the DSGE model; therefore the direction of causality is unambiguously from policy to productivity. The model is estimated and tested using simulation-based econometric methods (indirect inference). The results offer robust empirical evidence that temporary changes in policies underpinning the business environment can have long-lasting effects on economic growth.

Keywords: Economic growth, government policy, country studies, indirect inference
JEL Codes: O4, O5, O52, E1

1. INTRODUCTION

Endogenous growth theories have proliferated in the decades since Lucas declared the causes of growth an appropriate subject for obsession (Lucas, 1988).[1] 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, arguing that such 'barriers to entrepreneurship' stifle growth. However, these recommendations are controversial. Subsidies, tax credits, tax rate cuts and deregulation all have potentially high costs to society, and empirical work estimating their growth effects is dogged by some pervasive problems that undermine the results; in particular the problem of insufficient model identification, i.e. the lack of restrictions on the parameters of interest allowing one theory

[1] "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)

to be distinguished from others. This study takes a different approach in order to avoid this problem.

I investigate whether tax and regulatory policies affected economic growth in recent UK history (1970-2009) by acting as a barrier to entrepreneurship. Existing literature points to theoretical ambiguity over causation in this policy-growth relationship, which obscures the interpretation of regression-based empirical studies at the country level. Here a simulation-based testing and estimation method is applied to a structural macroeconomic model in which identification is assured, representing a novel approach to these issues.

In a Dynamic Stochastic General Equilibrium (DSGE) model of the United Kingdom, a systematic relationship between productivity and policy is derived from the optimality conditions. 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.[2] The bootstrapped model's implied behaviour is formally tested against the UK experience through Indirect Inference, which uses an auxiliary model to describe both simulated and 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 data. The approach throughout is therefore positivist.[3]

Focusing on a single country at the macroeconomic level, we bypass difficulties of heterogeneity associated with panel studies. The UK itself is an interesting case study, with reliable data for a 30-year period during which the country experienced significant variation in both economic performance and tax and regulatory policy.

The structural parameters of the growth model are estimated indirectly, by searching across the model's parameter space to 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 a particular numerical set of parameters. This is the first time that Indirect Inference methods have been applied to a growth model of the UK. The study is conducted using unfiltered data for all endogenous

[2] This is therefore a 'semi-endogenous' growth model in the broad sense of Jones (1995), as policy is not assumed to determine long-run growth rates in steady state.

[3] 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; cf. Friedman, 1953); that is, we claim that searching for macroeconomic models that stand up to empirical tests is a worthwhile and important exercise.

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 estimation results indicate a causal effect for tax and regulatory policy on productivity and output between 1970 and 2009. The policy environment is proxied by a weighted combination of top marginal personal income tax rates and indices of centralised collective bargaining and the mandated cost of hiring. The conclusions hold when corporate tax rates are used instead of top marginal income tax rates, and when tax rates are excluded.

A variance decomposition for the estimated model shows that policy is responsible for much of the endogenous variables' simulated variance. The power of the Indirect Inference test to reject a false hypothesis is high (Le et al. 2011, 2015), so these results constitute strong empirical support for the hypothesis that policies underpinning the business environment had a causal effect on UK total factor productivity growth in the past forty years.

The focus here on an entrepreneurial growth channel targeted by tax and regulatory policy is motivated by the credence given to this mechanism among policymakers. Entrepreneurship has been high on the growth policy agenda across OECD countries for well over a decade (Davis, 2008, p.36), and the UK government elected in 2010 endorsed the channel strongly in its 'Growth Strategy'. Its Plan for Growth (HM Treasury, 2011) emphasized growth through business start-up and operation, to be targeted by reducing "burdens" from tax and regulation in general, with specific reference to employment regulation.[4] The current government shows no sign of adjusting this strategy.

UK policymakers believe, therefore, that regulatory policy is a barrier to entrepreneurship and hence to growth.[5] Indeed, a deregulatory trend has gathered pace across the OECD since the World Bank began systematically to rank countries according to Ease of Doing Business

[4] The "overarching ambitions" are: 1) "to create the most competitive tax system in the G20"; 2) "to make the UK one of the best places in Europe to start, finance and grow a business" (p.5); 3) to stimulate investment and exports; 4) to "create a more educated workforce that is the most flexible in Europe". Note that human capital accumulation is last on this list and that even then, the fourth point conflates two workforce objectives: skill accumulation and labour market flexibility. This last is to be achieved by ensuring 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).

[5] 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.

(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.

Another important feature of the business environment is taxation. Taxes may distort investment decisions and hence macroeconomic performance, and this logic led to sharp cuts to personal and corporate income tax rates from the early 1980s in the UK (as in the US) as part of a broader programme of supply side policy reforms. However, in the World Economic Forum's 2010-2011 Global Competitiveness Report (GCR) tax rates were perceived as 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.[6,7]

In the current socio-economic climate when governments are required to spend without building up excessive debt, the temptation is to increase marginal tax rates at the top of the income distribution; this is also a natural response to increasing social inequality.[8] Therefore the question of whether top marginal tax hikes come with an attached growth penalty is of some relevance.

The paper is structured as follows. A brief overview of relevant literature 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, along with key data choices; the full model is derived in Appendix A. 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.

2. LITERATURE REVIEW

A variety of micro-based models exist of the process by which innovation raises productivity. In 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 barri-

[6] 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.

[7] This is a survey-based measure of perceptions. 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.

[8] The UK government raised the top rate of income tax in 2009 from 40 to 50p, the first increase in this band for over 20 years.

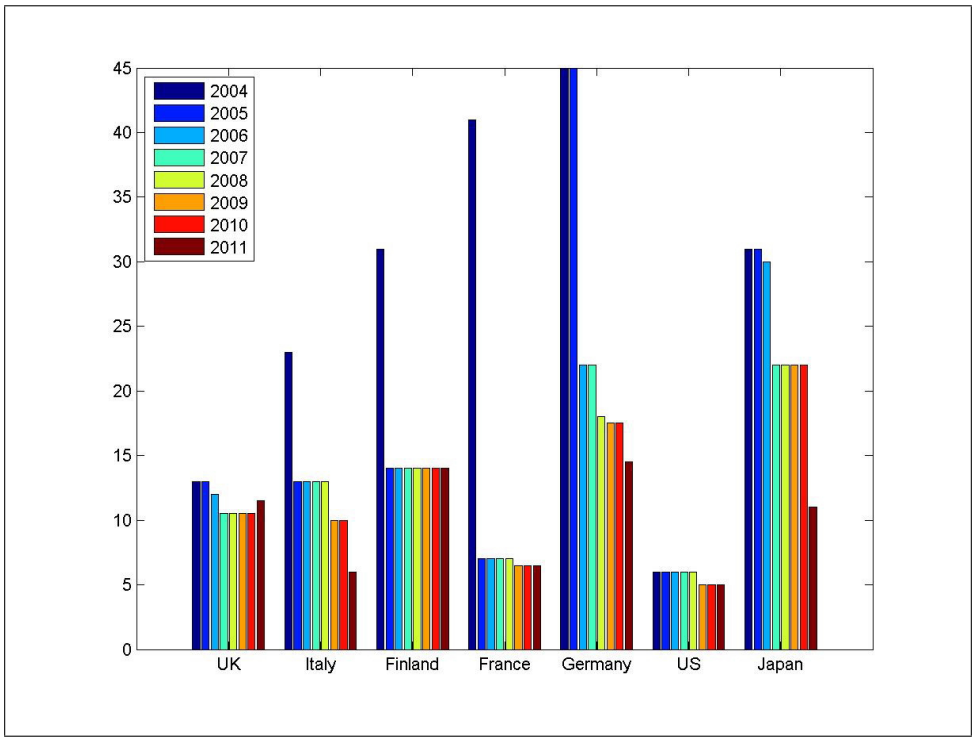


FIG. 1 Time Needed to Start a Business, Doing Business Indicators (World Bank)

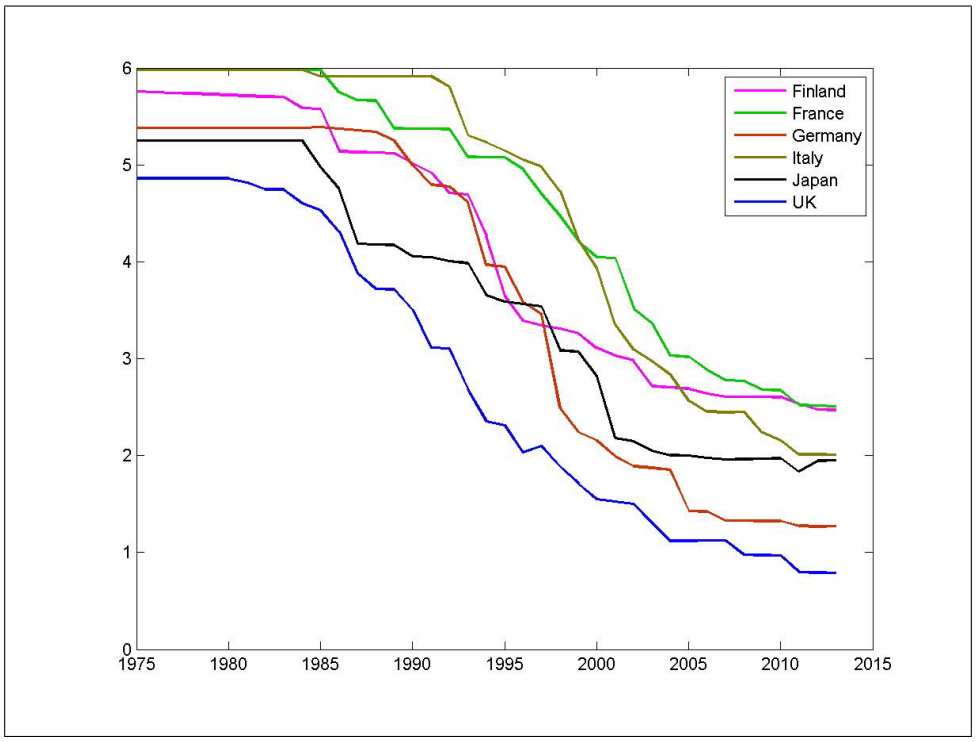


FIG. 2 Product Market Regulation, Network Sectors (Energy, Transport and Communications). Source, OECD.

ers to entry (such as regulation and tax) 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;[9] 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 macroeconomic 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

[9] 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.

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).

It is increasingly recognised that aggregate growth regressions in the style of Barro (1991) are of limited use when the goal is to test growth policy 'levers'.[10] These 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.[11]

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. In public choice theory, regulation is a tool of malign government for extracting rents (e.g. Stigler, 1971), implying a negative relationship between regulation and growth. A third theory is 'government failure' whereby regulation, though benignly intended, negatively impacts market outcomes due to flawed design or enforcement.[12] Distinguishing between these theories in the data is difficult since government disposition and competence is unobserved.[13]

[10] Such regressions characterise policy as an exogenous variable, and growth rates are regressed on this and other control variables in a cross-country or panel setup.

[11] Some favour GMM system methods, which infer that an endogenous variable's own lags are appropriate instruments from assumptions about dynamic relationships in the model; these too are controversial. Angrist and Krueger (2001) call this approach "mechanical and naive," based as it is on "atheoretical and hard-to-assess assumptions" about the lag structure.

[12] 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.

[13] 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

A straightforward macro-level regression of growth on regulation will not distinguish between different causal hypotheses, may suffer from endogeneity bias, and may admit multiple interpretations. Some address this 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).[14]

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).

Many theoretical predictions exist likewise for the tax-growth and tax- entrepreneurship relations, again reflected in a lack of empirical consensus. 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).[15] Of course, negative growth effects arise in theory not from average but from marginal tax rates, which differ in OECD economies due to progressivity in the schedule. However, the in-

(causation from higher growth to lower regulation).

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

[15] The force of this positive tax-growth mechanism will not be monotonic if there is an underlying Laffer curve.

herent difficulties in measuring effective marginal rates means average tax rates are still widely included as a regressor.[16] Tax is a highly politicised area; rates certainly respond to political pressures, which respond in turn to the state of the economy (Slemrod, 1995). Therefore regressions with tax instruments on the right hand side and growth on the left are vulnerable to criticisms of endogeneity. See Myles (2009a,b) for comprehensive surveys of empirical work on the tax-growth relationship.

The theoretical impact of tax on entrepreneurship is equally indeterminate; high marginal tax rates may discourage the risk neutral entrepreneur, but insure the risk averse entrepreneur against failure (Gentry and Hubbard, 2000). For regressions of entrepreneurship on marginal tax rates see the overview in Baliamoune-Lutz and Garello (2014, p. 169); the sign and magnitude of the estimated effects differs broadly 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, the macro-level empirical literature on these issues throws up a variety of estimates and of policy interpretations for those estimates. 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.

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).[17]

A different approach to the macroeconometrics of policy and growth is therefore warranted. Rodrik (2012, p.148) recommends that we "take the theories that motivate our empirical analyses more seriously." 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." This is the approach taken here. We derive the relationship from tax and regulatory policy to growth within a structural model, and see whether that data generating

[16] 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.

[17] 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).

process as a whole could have produced the observed UK productivity experience.

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). The 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 isolate whether this policy hypothesis alone has caused the rejection.

The full model is given in Appendix A. It is a two-country model (Armington, 1969; cf. Feenstra et al. 2014) with a single industry; there is one broad type of good traded internationally, but the product of the home goods sector is differentiated from the foreign product. The home country is the UK 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. By suppressing the nominal side of the economy we bypass the issue of monetary and exchange rate regime changes in the UK, which have been frequent during the sample; this RBC model can account for UK real exchange rate behaviour without nominal frictions (see Appendix D results).

The home economy features a representative consumer, a representative firm, and a government which spends on welfare transfers 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 capital purchases through bond issue. The consumer is also the shareholder of the firm.

Productivity is non-stationary (Appendix A, eq. 31) and depends on time spent in innovative activity z_t, the consumer's choice (cf. Lucas, 1990). This activity is subject to a proportional cost due to government policy, τ'_t. In this paper, z_t is conceived of as entrepreneurship. A sizeable literature is devoted to finding a precise and workable definition of this 'activity.' Here we follow the synthesis definition of Wennekers and Thurik (1999), that

entrepreneurship is the "ability and willingness [...] to perceive and create new economic opportunities [...] and to introduce their ideas in the market, in the face of uncertainty and other obstacles [...] it implies participation in the competitive process" (p. 46-47).

In a broad sense the entrepreneurship growth channel encompasses business activities which push forward the production possibility frontier (the creative responder/destructor identified by Schumpeter, 1947, 1942) or raise the average productivity level in the economy (the arbitrageur emphasized by Kirzner, 1973), perhaps by implementing foreign technologies at home. Of course there is no explicit entry or exit in this model, and no explicit international spillovers. The firm exists exogenously and the share-holder entrepreneur donates all ideas resulting from z_t to her firm, with full excludability; we abstract from public goods features of TFP. The entrepreneur (as owner of the firm) captures the full return on her investment in z_t, except to the extent that taxes and regulatory costs reduce those returns. These costs are reflected in the model by τ'_t, discussed further in Section 3.

Entrepreneurship is thus added 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).[18] 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.[19]

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 judged on "descriptive accuracy" but on "analytical relevance" (Friedman, 1953, p.166) and, in general, simpler

[18] Acs et al. (2013) take a similar position. "this model is not intended to describe the entrepreneurial process at the micro level but rather models its implications at the macro level." (p.777)

[19] "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)

theories (provided they can explain the phenomena of interest) are preferable to complex theories. 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 is left to future work to examine what sort of micro-based process could be driving it.

A systematic relation between productivity growth and τ_t' is derived from the model's optimality condition with respect to the entrepreneurship choice (See Appendix A, eq. 38). Entrepreneurship itself is therefore 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 loglinearised system is listed in Appendix A, with details of the stochastic processes. There are 11 exogenous processes in the model modelled as ARIMA$(1, 0, 0)$. These are shocks to real interest rates, productivity, labour demand, capital demand, wages, export demand and import demand; four exogenous variables treated in the same way are foreign consumption demand, foreign real interest rates, government spending and the policy variable, τ_t'. Productivity itself (A_t, the Solow residual in the production function) is modelled as a random walk with drift depending on its AR(1) shock and also on τ_t'. The drift term in A_t is removed from the analysis, as are any deterministic trend terms in the residuals.

Since the drift in productivity is exogenous and the penalty variable τ_t' is trend stationary, the growth rate of A_t in the absence of shocks is constant. However, that is not the focus here. 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 in the residuals; but the steady state growth behaviour of the economy in our finite sample is not the empirical issue of interest. We 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.

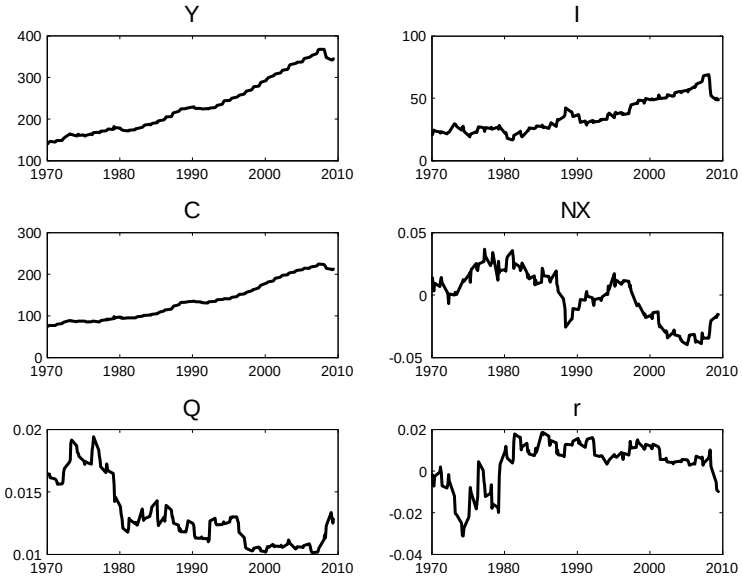


FIG. 3 Key UK data, quarterly. Real GDP (Y), Investment (I), Consumption (C) in £bn; Net Exports/GDP (NX), Relative Price of Imports to Exports (Q), and Domestic Real Interest Rate (r).

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.[20] 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). 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.

[20] See discussion in Canova, 2014.

3.2.1. Measuring Policy

In the model, the policy variable is a systematic driver of the productivity level via 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. 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. 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 proxying the policy environment in which entrepreneurs must exist at the macro-level, while also being frequent enough and spanning 1970-2009.[21]

Excessive regulatory or tax burdens can lead to "unproductive" entrepreneurship (Baumol, 1990) 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 ideally excludes 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

[21] 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.

may simultaneously encourage unproductive entrepreneurship in others.[22] 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, wasting 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 empirical.

3.2.2. Data for the Policy Variable

A less aggregated measure of τ' minimizes the risk of different component indices offsetting one another within the overall index and so obscuring the policy conclusions. Therefore I have been parsimonious in selecting components to combine into a single index. The UK index 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 (1970-2009). The original data source for the CCB index is the World Economic Forum's Global Competitiveness Report, while the MCH index is constructed from World Bank Doing Business data. The series are interpolated to a higher frequency using UK trade union membership rates, via the Denton method. The construction of the policy indices is described in detail in Appendix B. They are combined to give a 'labour market regulation' (LMR) indicator, which is higher when labour markets are less flexible (Figure 4).

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

[22] 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.

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 an 'effective' tax rate on entrepreneurs for the period 1970-2009, I use the top marginal income tax rate to proxy the extent to which the proceeds of entrepreneur activity are not appropriable by the individual entrepreneur (or her firm). 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.[23] 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.[24]

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

[23] 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.

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

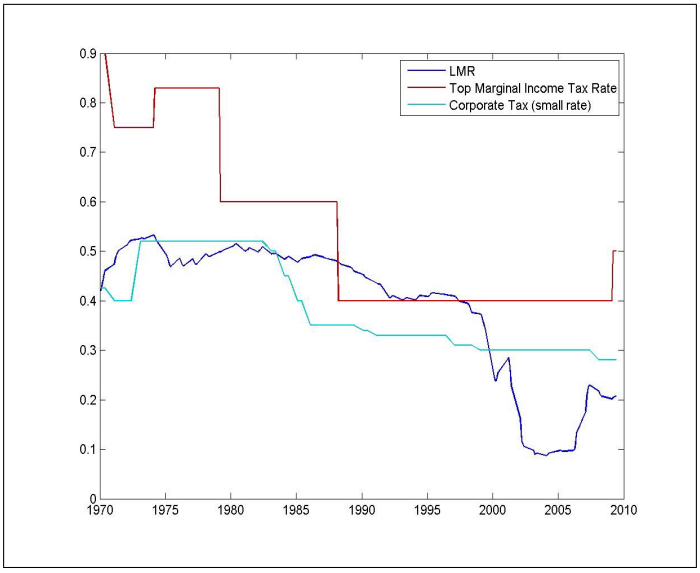


FIG. 4 Top Marginal Income Tax Rate, Labour Market Regulation Indicator, and Corporation Tax (SME rate)

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 4. 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 5).[25]

The index $\tau(1)$ falls over the sample period, though not in a regular way due to the steps in the marginal income tax rate. On visual inspection, the series could be a random walk with drift or a trend stationary process, perhaps with a structural break around 2002. 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 6. This shows 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, but through the Indirect Inference procedure described in Section 4;

[25] Series components are highly correlated (see Appendix B).

[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.

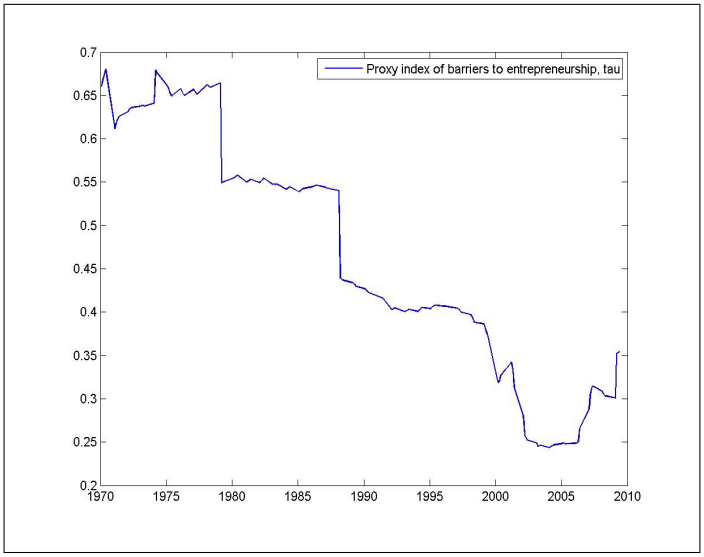


FIG. 5 Evenly weighted combination of top marginal income tax rates and the labour market regulation indicator, $\tau(1)$

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., 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) 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.

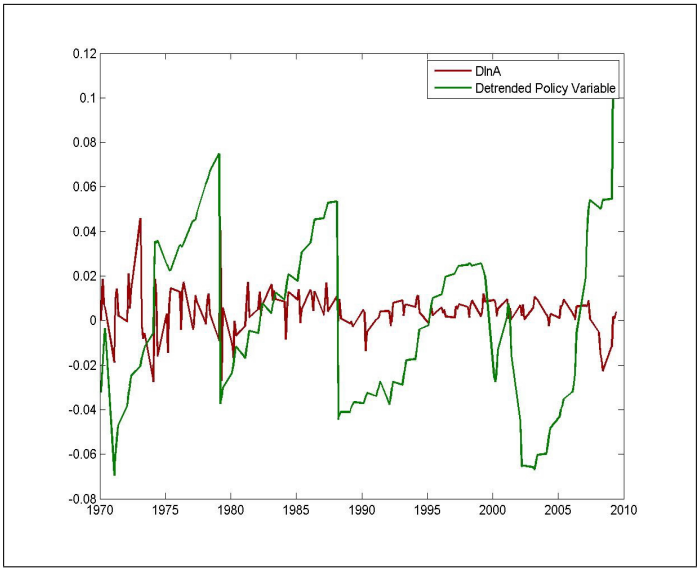


FIG. 6 Linearly Detrended Policy Variable $\tau(1)$ and $D \ln A$

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

[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 Appendix A.

[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 $J = 1000$. A larger number, say $10,000$, would be preferable, but at a prohibitive computational cost for the full estimation process.

$WS(\theta)$ is obtained:

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

$\overline{a_j(\theta)}$ is the arithmetic mean of the J estimated vectors and $W(\theta) = \Omega(\theta)^{-1}$ is the inverse of the estimated variance-covariance matrix.[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 observed data.

Le et al. (2015) 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 quite confident that false models will be rejected by this test.

The indirect inference test is the basis for the indirect estimation carried out in Section 5. The 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, 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

[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.

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).[33]

In Section 5, a 'simulated annealing' algorithm is employed to perform the indirect inference Wald test for points inside the parameter space. 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 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.[34] An auxiliary model with stationary errors is required when endogenous variables are non-stationary by virtue of their dependency on non-stationary exogenous variables. Therefore a Vector Error Correction Model is appropriate here. In Appendix C it is shown, following Meenagh et al. 2012, 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) 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).[35] The Directed Wald involves selecting certain endogenous variables that are key for evaluating the theory being tested. In this

[33] 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).

[34] 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.

[35] Strictly speaking, the full Wald would also be based on estimation of a higher order VARX, i.e. 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).

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 1 is the auxiliary model used in the empirical work.[36]

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

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

[36] 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.

$b_{21} = 0$ 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.[37] OLS is a biased estimator of the auxiliary model due to the presence of lagged endogenous variables as regressors, so no emphasis is placed on the magnitudes of the estimated coefficients. The relevant question is whether the bias of the auxiliary model estimation procedure affects the properties of the test. Since the same auxiliary model and estimator is used for the description of the simulated data and the observed data, the same bias applies for both; hence the power of the test should not be affected. In other words, we ask whether the model-implied OLS-estimated-VAR would generate the same OLS-estimated-VAR as the actual data. Monte Carlo experiments confirm that the power is high (Le et al. 2011, p.2101).

5. EMPIRICAL WORK

Given the data choices in Section 4, the model assumes that a temporary (though persistent) change in the policy environment for entrepreneurs causes a permanent change in the productivity level, implying a transitional change in the growth rate. We see whether this data generating process can accommodate UK productivity and output behaviour between

[37] 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.

1970 and 2009.

Section 5.1 presents the results of the indirect estimation for this model. A variance decomposition is then conducted using the model, in which the shocks to τ' and the shocks to the AR(1) productivity error 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 1 and 2). 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). Long-run ratios are calibrated to UK post-war averages (Table 2).[38] The long-run quarterly growth rate of capital is assumed to be equal to output growth. We assume $\frac{K}{Y} = 3$ so that $\frac{K}{C} = 3.\frac{Y}{C} = 5.196$. 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.[39]

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 4; a symbol key is provided in Table 3. The

[38] To ensure consistency between $\frac{Y}{C}$ and 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 $\frac{M}{C} = \frac{M}{Y}.\frac{Y}{C} = 0.369$.

[39] For instance, while the presence of ζ (a fixed coefficient in the adjustment cost function) and d (the firm's discount factor) in the coefficients of the linearised capital demand equation (eq. 47) allows some empirical flexibility, $\zeta_3 = 1 - \zeta_1 - \zeta_2$ is an important constraint to ensure consistency with the long run. In steady state when all temporary shocks have died out and there are no adjustment costs, capital and output must grow at the same rate; since by detrending the shocks we remove the deterministic growth path, we require $K = Y$, so that adding back the long run growth path will imply $K(1+g_k)^t = Y(1+g_y)^t$ and $g_k = g_y$, and the long run capital-output ratio is constant.

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 1
Fixed Parameters

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

TABLE 2
Long Run Ratios, Fixed Throughout

ρ_1	CRRA coefficient on consumption
ρ_2	CRRA coefficient on leisure
θ_0	Preference weight on consumption in utility function
ω	Home bias in consumption
ω_F	Foreign equivalent of ω
σ	Import demand elasticity
σ_F	Elasticity of substitution, domestic and imported consumption good
ζ_1	Impact of lagged capital stock on current capital demand (natural logs)
ζ_2	Impact of expected capital on current capital
ζ_3	Impact of output on current capital
ζ_4	Impact of the current real interest rate on current capital
c_1	$\partial z_t / \partial \tau_t'$
b_1	$\partial [d \ln A_t] // \partial \tau_t'$

TABLE 3
Key to Estimated Parameters

test statistic gives a Wald percentile of 72, well within the non-rejection area of the bootstrap distribution; we could equally express this as a p-value of 0.28. 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. The implied AR(1) coefficients for the exogenous stochastic processes are reported in Table 5. The estimated import and export elasticities with respect to a change in relative price sum to 2.337, satisfying the Marshall-Lerner condition.[40] The estimates are also consistent with US estimates obtained by Feenstra et al. (2014), and with UK estimates from 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 expected capital, ζ_2, at 0.3349 implies a 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. The impact of a policy shock at t on the change in log productivity next quarter is estimated at -0.1209.

Given these parameter values, a variance decomposition is calculated for $\Delta \ln A_t$ (for which only the τ' innovation and the independent productivity innovation, ε_A, are relevant), and also for the other endogenous variables.[41] Over the simulation period we calculate the variation induced in the endogenous variables by each of these shocks separately, seeing which generate relatively more volatility in the model. This gives 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 6. Row 8 of this table shows that the policy variable plays a significant part in generating variation in the level of all variables, particularly output, consumption, labour supply (and

[40] The current account balance improves when the real exchange rate depreciates.

[41] There are eleven (mostly highly persistent) stationary shocks, some affecting net foreign assets (a unit root endogenous variable); and two enter the non-stationary productivity process. Therefore some non-stationarity is introduced into the system even by the stationary shocks. τ' and ε_A also engender significant non-stationarity in the simulations. However, we can be confident that variances taken over the finite sample are bounded.

hence the producer cost of labour $\tilde{w}$), exports 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 role in the dynamics.

Given the importance of τ' relative to the other shocks, the Indirect Inference test was repeated on the model (with this coefficient set) with a smaller set of shocks, including only shocks to the real interest rate and productivity, in addition to the exogenous variables τ', government spending, foreign consumption and the foreign real exchange rate. The Wald statistic for this model with fewer shocks falls in the 92nd percentile of the distribution, within the non-rejection region.

The model with this set of coefficients was also tested using some alternative auxiliary models, in which more endogenous variables are included. This tests 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 particularly well for certain endogenous variables that are key for policymakers, including output and productivity on the real side, and real interest rates and real exchange rates on the relative price side. 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.[42]

The results presented above are for $\tau(1)$; see Appendix D for robustness checks regarding the policy variable.

[42] It has been theorised elsewhere that the policy incentives ascribed to entrepreneurial activities here may promote innovation through formal R&D activity (see e.g. Jaumotte and Pain, 2005). The results found in Section 5 for tax and regulatory reform may work through the R&D channel as well as through 'entrepreneurship'. We attempted to distinguish these channels by including the top rate of personal income tax in $\tau(1)$, on the basis that personal income tax rates are more directly related to the entrepreneur's decision process than to decisions around R&D. However, the precise innovation activities through which the policy $\tau(1)$ translates into productivity effects remain open in this study. Rather than 'barriers to entrepreneurship', the framework policies investigated here can be more neutrally termed 'barriers to business'.

$\boldsymbol{\rho}_1$	$\boldsymbol{\theta}_0$	$\boldsymbol{c}_1$	$\boldsymbol{\rho}_2$	$\boldsymbol{\omega}$	$\boldsymbol{\sigma}$	$\boldsymbol{\sigma}_F$
0.9712	0.5267	−0.0568	1.5198	0.5431	0.7676	0.8522
$\boldsymbol{\omega}_F$	$\boldsymbol{\zeta}_1$	$\boldsymbol{\zeta}_2$	$\boldsymbol{\zeta}_3$	$\boldsymbol{\zeta}_4$	$\boldsymbol{b}_1$	$\boldsymbol{Wald\%}$
0.8819	0.6359	0.3349	0.0240	0.2365	−0.1209	72.23

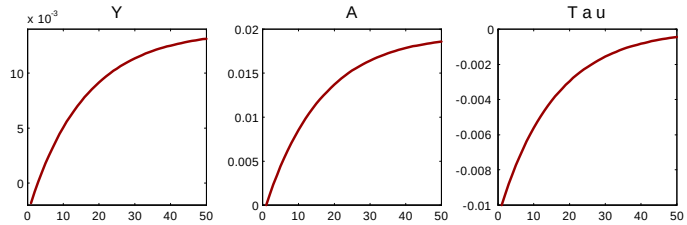
TABLE 4
Wald Minimising Coefficient Values for Tau(1) Model

$\boldsymbol{e}_r$	$\boldsymbol{e}_A$	$\boldsymbol{e}_N$	$\boldsymbol{e}_K$	$\boldsymbol{e}_w$	$\boldsymbol{e}_X$
0.8713	0.237	0.898	0.990	0.959	0.959
$\boldsymbol{e}_M$	$\boldsymbol{\tau}$	$\boldsymbol{C}^*$	$\boldsymbol{r}^F$	$\boldsymbol{G}$	
0.951	0.968	0.918	0.967	0.935	

TABLE 5
AR(1) coefficients for structural shocks given Wald minimising parameter set, Tau(1) Model

	$\mathbf{r}$	$\mathbf{Y}$	$\mathbf{N}$	$\mathbf{K}$	$\mathbf{C}$	$\mathbf{w}$	$\widetilde{\mathbf{w}}$	$\mathbf{X}$	$\mathbf{M}$	$\mathbf{Q}$	$\mathbf{b}^F$	$\mathbf{d}(\mathbf{A})$
$\mathbf{e}(\mathbf{r})$	0.1833	0.0016	0.0080	0.0033	0.0370	0.0471	0.0005	0.0118	0.0800	0.0114	0.0396	0
$\mathbf{e}(\mathbf{A})$	0.0453	0.1320	0.1056	0.0244	0.1018	0.0611	0.1339	0.1342	0.0880	0.1298	0.0087	0.8146
$\mathbf{e}(\mathbf{N})$	0.0150	0.0012	0.0111	0.0002	0.0012	0.0251	0.0086	0.0005	0.00001	0.0005	0.0008	0
$\mathbf{e}(\mathbf{K})$	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
$\mathbf{e}(\mathbf{X})$	0.0174	0.0044	0.0511	0.00002	0.0704	0.2564	0.0004	0.0452	0.2395	0.0653	0.5242	0
$\mathbf{e}(\mathbf{M})$	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 6
Variance Decomposition for Tau(1) Model Given Estimated Coefficients



6. GROWTH EPISODE AFTER A POLICY REFORM

Impulse response functions for a one-off 1 percentage point reduction in $\tau(1)$ illustrate the resulting growth episode. Although the policy shock is temporary, it affects the level of productivity permanently and shocks the growth rate above its deterministic rate for a lengthy period (Figure 6).[43] The 1 percentage point $\tau(1)$ shock is gradually reversed over time, taking roughly 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 1.6 percentage points higher than its no-shock level after 18 years. This translates to an average higher growth rate of 0.09 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 0.17 for two decades.[44] Relating this to the UK data, Figure 6 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 rate 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.[45]

[43] Labour supply falls initially, as the lower opportunity cost of z makes labour relatively less attractive. This causes output to falls at first, but as higher innovation in period 1 causes higher productivity next period, output rises from $t = 2$. Over the simulation, real wages rise to offset the income effect on labour supply from the productivity increase. Eventually Y and w converge to higher levels. Productivity growth also triggers a real business cycle upswing, not illustrated.

[44] The shock's consequence is so long-lasting because capital takes a long time to react fully to the rise in TFP, due to adjustment costs.

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

7. CONCLUSION

An identified model was set up in which policy reform causes short- to medium-run growth episodes. The simulated features of this model – as summarised by an auxiliary model – were discovered to be close (in a formal sense) to the UK data features, through an indirect inference Wald test. This is evidence that temporary movements in tax and regulatory policy around trend drove short-run productivity growth between 1970 and 2009. Since policy shocks in the model are exogenous and uncorrelated with other shocks in the model, there is no ambiguity surrounding causation.

The tax and regulatory policy environment for this period is proxied by a weighted combination of the top marginal rate of personal income tax and a labour market regulation indicator. The results show that these proxies for 'barriers to entrepreneurship' affected UK TFP growth negatively, consistent with the argument of Crafts (2012), Card and Freeman (2004) and Acs et al. (2009).

Since the indirect inference test has been shown elsewhere to have strong statistical power (Le et al., 2015), the results reported in Table 11 are a robust addition to the empirical record on this question. The causal mechanism embedded in the DSGE model – from an increase in labour market frictions and marginal tax rates to a decrease in productivity growth – is integral to the model data generating process. Therefore if in fact (in some alternative 'true' model) shocks to the tax and regulatory policy index increased productivity growth rather than decreasing it, or had no perceptible effect, this model would be rejected by the test.

The implication is that for policymakers to focus on knowledge creation policy (i.e. incentivising R&D) while ignoring incentives around entrepreneurship would indeed be "seriously misguided" (Acs and Sanders, 2013, p. 787). The results indicate that the creation of an environment in which businesses operate flexibly and innovatively was important to the UK macroeconomic performance in 1970-2009.

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APPENDIX A: MODEL DERIVATION

A.1. Consumer Problem

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

$$U = \max E_0[\sum_{t=0}^{\infty} \beta^t u(C_t, x_t)] \tag{2}$$

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

$$u(C_t, x_t) = \theta_0 \frac{1}{(1-\rho_1)} \gamma_t C_t^{(1-\rho_1)} + (1-\theta_0) \frac{1}{(1-\rho_2)} \xi_t x_t^{(1-\rho_2)} \tag{3}$$

$\rho_1, \rho_2 > 0$ 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; $0 < \theta_0 < 1$ is a preference weighting on consumption.

The agent divides time between leisure, labour supplied to the firm for real wage w_t, and z_t which is unpaid at t but has future returns. The time endowment is normalised at one:

$$N_t + x_t + z_t = 1 \tag{4}$$

Leaving aside z_t for now, the agent chooses of leisure versus non-leisure activity, consumption, and investment in domestic and foreign bonds (b_{t+1}, b^f_{t+1}), bonds issued by the firm to finance its capital ($\tilde{b}_{t+1}$), and new shares (S^p_t) at price (q_t). Bonds are issued at unit price. Dividends (d_t) are earned on S^p_{t-1}. 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 T_t is not yet relevant. The real terms budget constraint is:

$$\begin{gathered} C_t + b_{t+1} + Q_t b^f_{t+1} + q_t S^p_t + \tilde{b}_{t+1} = w_t N_t - T_t + b_t(1 + r_{t-1}) + \\ Q_t b^f_t (1 + r^f_{t-1}) + (q_t + d_t) S^p_{t-1} + (1 + \hat{r}_{t-1}) \tilde{b}_t \end{gathered} \tag{5}$$

Q_t is a unit free measure of the price of the foreign consumption good relative to the general price level P_t at home defined as $Q_t = \frac{P^f_t}{P_t}.\hat{E}_t$. $\hat{E}_t$ is the nominal exchange rate.[46] Assuming $\hat{E}_t \equiv \hat{E} \equiv 1$, Q_t is the import price relative to the domestic CPI (i.e. the inverse of the real exchange rate).[47]

The first order conditions of the consumer problem yield the Euler equation (6), the intratemporal condition (7),[48] real uncovered interest parity (RUIP, 8), and the share price formula (9). 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.

$$\frac{1}{(1+r_t)} \gamma_t C_t^{-\rho_1} = \beta E_t[\gamma_{t+1} C_{t+1}^{-\rho_1}] \tag{6}$$

$$\frac{U_x}{U_c}|_{U=0} = \frac{(1-\theta_0)\xi_t x_t^{-\rho_2}}{\theta_0 \gamma_t C_t^{-\rho 1}} = w_t \tag{7}$$

$$(1 + r_t) = E_t \frac{Q_{t+1}}{Q_t}(1 + r^f_t) \tag{8}$$

[46] The foreign bond b^f_{t+1} is a real bond, i.e. it costs the amount as a unit of the foreign consumption basket (C^*_t), i.e. P^*_t, the foreign CPI. In domestic currency, this is $P^*_t \hat{E}_t$. As everything in the budget constraint is relative to P_t, and assuming that $P^*_t \simeq P^f_t$ (i.e. exported domestic goods have little impact on the foreign country) the unit cost of the real foreign bond is Q_t. The domestic bond is likewise equivalent to a unit of the home consumption basket.

[47] 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, i.e. a real exchange rate depreciation.

[48] Later it will be shown that the return on labour time, w_t, is equal at the margin to the return on z_t.

$$q_t = \frac{q_{t+1} + d_{t+1}}{(1 + r_t)} = \sum_{i=1}^{\infty} \frac{d_{t+i}}{\prod_{j=0}^{i-1}(1 + r_{t+j})} \tag{9}$$

Equation 9 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 marginal returns on all assets (S_t^p, b_{t+1}, $\tilde{b}_{t+1}$ and b_{t+1}^f) are equal.

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.[49] The level of consumption C_t chosen above must satisfy the expenditure constraint on consumption,

$$C_t = p_t^d C_t^d + Q_t C_t^f \tag{10}$$

where p_t^d and Q_t are domestic and foreign prices relative to the general price level, P_t. Given the identity in equation 10, the consumer chooses C_t^d and C_t^f to maximise $\tilde{C}_t$ according to the following CES aggregator utility function (equation 11), subject to the constraint that $\tilde{C}_t \leqslant C_t$.

$$\tilde{C}_t = [\omega(C_t^d)^{-\rho} + (1-\omega)\varsigma_t(C_t^f)^{-\rho}]^{-\frac{1}{\rho}} \tag{11}$$

At the point of the maximum the constraint is binding and the 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 preference for domestic goods is captured by $0 < \omega < 1$. Demand for imports features a stochastic shock, ς_t . The substitution elasticity between domestic and foreign varieties is constant at $\sigma = \frac{1}{1+\rho}$. First order conditions imply the relative demands for imports (equation 12) and for domestic good (13).

$$\frac{C_t^f}{C_t} = \left(\frac{(1-\omega)\varsigma_t}{Q_t}\right)^{\sigma} \tag{12}$$

$$\frac{C_t^d}{C_t} = \left(\frac{\omega}{p_t^d}\right)^{\sigma} \tag{13}$$

Given equation 12, foreign demand for domestic goods (exports) relative to general foreign consumption is symmetric

$$(C_t^d)^* = C_t^* \left(\left(1-\omega^F\right)\varsigma_t^*\right)^{\sigma^F} (Q_t^*)^{-\sigma^F} \tag{14}$$

where * signifies a foreign variable and ω^F and σ^F are respectively foreign equivalents to home bias and the substitution elasticity between domestic and imported goods. Q_t^* is the foreign equivalent of Q_t, the ratio of the import price to the CPI, and $\ln Q_t^* \simeq \ln p_t^d - \ln Q_t$.[50] An expression for p_t^d follows from maximised equation 11 where $\tilde{C}_t = C_t$ combined with functions 12 and 13:

$$1 = \omega^{\sigma}(p_t^d)^{\rho\sigma} + [(1-\omega)\varsigma_t]^{\sigma} Q_t^{\rho\sigma} \tag{15}$$

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

$$\ln p_t^d = \hat{k} - \left(\frac{1-\omega}{\omega}\right)^{\sigma} \frac{1}{\rho} \ln \varsigma_t - \left(\frac{1-\omega}{\omega}\right)^{\sigma} \ln Q_t \tag{16}$$

[49] The consumer gets utility from an overall amount of each industry product 'type', allocating her budget between each type of good (simply C_t in the one-industry case); she then decides how to divide that spending allocation across the differentiated products within that type (here C_t^d and C_t^f)

[50] 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.

where $\hat{k}$ is a constant of integration. Using this relationship the export demand equation is (for $\sigma = 1$)

$$\ln(C_t^d)^* = \check{c} + \ln C_t^* + \sigma^F \frac{1}{\omega} \ln Q_t + \varepsilon_{ex,t} \tag{17}$$

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 constraints, the real balance of payments constraint is satisfied so that the current account surplus (real net exports plus income flows on foreign assets) and capital account deficit (the decrease in net foreign assets) sum to zero. Expressed in real terms, the balance of payments is

$$\Delta b_{t+1}^f = r_t^f b_t^f + \frac{p_t^d EX_t}{Q_t} - IM_t \tag{18}$$

A.2. Firm Problem

The firm produces final goods via a Cobb Douglas function with constant returns to scale technology and diminishing marginal products to labour and capital:

$$Y_t = A_t K_t^{1-\alpha} N_t^{\alpha} \tag{19}$$

A_t is total factor productivity (TFP). The firm also faces convex adjustment costs to capital, taking a quadratic form. It undertakes capital investment, raising funds for new capital by issuing debt ($\tilde{b}_{t+1}$) at t, costing $\hat{r}_t$ 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 the return demanded by debt-holders, capital depreciation δ, and adjustment costs represented by $\tilde{a}_t$.[51] 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 input prices, capturing random movements in marginal tax rates, e.g. depreciation allowances or national insurance. From the consumer's first order conditions it follows that $\hat{r}_t = r_t$. Substituting for $\tilde{b}_{t+1} = K_t$, the profit function is:

$$\pi_t = Y_t - K_t(r_t + \delta + \kappa_t) - \frac{1}{2}\zeta(\Delta K_t)^2 - (\tilde{w}_t + \chi_t)N_t \tag{20}$$

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

The firm maximises expected profits subject to these constraints, choosing capital (K_t) and labour (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:

$$\mathcal{L}_0 = E_0 \sum_{t=0}^{\infty} d^t E_t \left\{ Y_t - K_t(r_t + \delta + \kappa_t) - \frac{1}{2}\zeta(\Delta K_t)^2 - (\tilde{w}_t + \chi_t)N_t \right\} \tag{21}$$

ζ is a multiplicative constant affecting adjustment costs, while d is the firm's discount factor (these parameters allow some empirical flexibility when the model is calibrated - see Section 5 for discussion). The first order condition for K_t shows that the marginal product of capital (net of adjustment costs and depreciation) is equal to its unit price, plus cost shock.

$$(1-\alpha)\frac{Y_t}{K_t} - \delta - \zeta\Delta K_t + d\zeta E_t(\Delta K_{t+1}) = r_t + \kappa_t \tag{22}$$

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

This gives a non-linear difference equation in capital.

$$K_t = \frac{1}{1+d}K_{t-1} + \frac{d}{1+d}E_t K_{t+1} + \frac{(1-\alpha)}{\zeta(1+d)}\frac{Y_t}{K_t} - \frac{1}{\zeta(1+d)}(r_t+\delta) - \frac{1}{\zeta(1+d)}\kappa_t \tag{23}$$

The firm's investment, I_t, follows via the linear capital accumulation identity:

$$K_t = I_t + (1-\delta)K_{t-1} \tag{24}$$

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

$$N_t = \alpha.\frac{Y_t}{\tilde{w}_t + \chi_t} \tag{25}$$

Internationally differentiated goods introduce a wedge between the consumer real wage, w_t, and the real unit cost of labour for the firm, $\tilde{w}_t$. The real cost of labour faced by the domestic firm is the nominal wage W_t relative to the value of the domestic good, P_t^d, while the real wage in the consumer budget constraint is the nominal wage W_t relative to general prices (the price P_t of the bundle combining domestic and imported goods). Since $p_t^d \equiv \frac{P_t^d}{P_t}$, the wedge is

$$p_t^d = \frac{w_t}{\tilde{w}_t} \tag{26}$$

implying, via 16, the relationship in equation 27.

$$\ln w_t = \hat{k} + \ln \tilde{w}_t - \frac{1-\omega}{\omega}\ln Q_t - \frac{1-\omega}{\omega}\frac{1}{\rho}\ln \varsigma_t \tag{27}$$

A.3. Government

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

$$G_t + b_t(1+r_{t-1}) = T_t + b_{t+1} \tag{28}$$

T_t is revenue from consumers. The government borrows, issuing one period bonds. Each period the government raises tax revenues such that $T_t = G_t + r_{t-1}b_t$ and $b_t = b_{t+1}$. Therefore debt is fixed and government is fully solvent every period. Revenue T_t is as follows.

$$T_t = \tau_t z_t + \Phi_t \tag{29}$$

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.[52] 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.

$$\ln G_t = g_o + g_1 t + \rho_g \ln G_{t-1} + \eta_{g,t} \tag{30}$$

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

[52] It is possible that only a proportion $0 < \psi < 1$ of the penalty paid 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. In that case revenue is $\tilde{T}_t = \psi\tau_t z_t + \Phi_t$ while the consumer tax bill is $T_t = \tau_t z_t + \Phi_t$. Here ψ is assumed to be 1, though notionally it could vary stochastically.

A.4. Endogenous Growth

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

$$\frac{A_{t+1}}{A_t} = a_0 + a_1 z_t + u_t \tag{31}$$

where $a_1 > 0$. z_t is the systematic channel through which policy incentives, τ_t, can drive growth.[53] 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 (1990) where growth depends on the agent's decision to spend time accumulating human capital. Human capital enhances labour efficiency and increases earnings, though the return to labour (for a given level of human capital) is foregone while raising the human capital stock. The particular endogenous growth process used here is from Meenagh et al. (2007), adapted for a decentralised framework.

The consumer maximises utility in equations 2 and 3 with respect to z_t (taking all other choices as given), subject to budget and time constraints and the taxbill (equations 4 ,5 and 29)). Assume the consumer's shareholdings are equivalent to a single share in every period t:

$$S^p_{t-1} = S^p_t = \bar{S} = 1 \tag{32}$$

The assumption in 32 allows the substitution to be made in the budget constraint that $q_t S^p_t - (q_t + d_t)S^p_{t-1} = -d_t$.[54] Note that dividend income d_t for shareholders is revenue leftover after costs, i.e. profits.

The agent rationally expects z_t to raise his own consumption through his role as the firm's sole shareholder, knowing equation 31. This higher productivity is fully excludable and donated exclusively to the atomistic firm he owns; higher productivity is anticipated to raise household income via firm profits paid out as dividends. The agent assumes that his choice will not affect economy-wide aggregates; all prices are taken as given (note that the productivity increase is not expected to increase the consumer real wage here, though it does so in general equilibrium).[55]

The first order condition is:

$$\frac{dL}{dz_t} = 0 = -\beta^t \lambda_t w_t - \beta^t \lambda_t \tau_t + E_t \sum_{i=1}^{\infty} \beta^{t+i} \lambda_{t+i} . \frac{d\ d_{t+i}}{dz_t} \tag{33}$$

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 costs to be paid (higher at

[53] All other factors - e.g. human capital or firm specific R&D investment - are in the error term.

[54] Each period the consumer demands S^p_t and the price per share must ensure that the number of shares supplied (normalised at one for all t) are held by the consumer. The value per share given in equation 9 is then the value of the firm as a whole.

[55] $1 = N_t + x_t + z_t$ so a full set of conditions will give indifference relations between z_t and x_t, between x_t and N_t, and between z_t and N_t. The intratemporal condition gives the indifference margin between x_t and N_t; here I focus on the margin between z_t and N_t, leaving the z_t - x_t margin implied. Therefore the substitution $N_t = 1 - x_t - z_t$ can be made in the budget constraint.

t in proportion to the increase in z_t), and expected dividend income.[56] With substitution from 31:

$$\beta^t \gamma_t C_t^{-\rho_1} w_t = \frac{a_1}{a_0 + a_1 z_t + u_t} . E_t \sum_{i=1}^{\infty} \beta^{t+i} \gamma_{t+i} C_{t+i}^{-\rho_1} Y_{t+i} - \beta^t \lambda_t \tau_t \tag{35}$$

τ_t 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.[57] Substituting again from 31 for z_t yields

$$\frac{A_{t+1}}{A_t} = a_1 . \frac{E_t \sum_{i=1}^{\infty} \beta^i \gamma_{t+i} C_{t+i}^{-\rho_1} Y_{t+i}}{\gamma_t C_t^{-\rho_1} (w_t + \tau_t)} \tag{36}$$

Assume $\gamma_t = \rho_\gamma \gamma_{t-1} + \eta_{\gamma,t}$, and $\rho_1 \simeq 1$, and 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 $i > 0$.[58] The expression becomes

$$\frac{A_{t+1}}{A_t} = a_1 . \frac{\frac{\beta \rho_\gamma}{1-\beta\rho_\gamma} \cdot \frac{Y_t}{C_t}}{\frac{w_t}{C_t}(1+\tau_t')} \tag{37}$$

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 (the opportunity cost of spending time outside regular work). τ_t' is unit free with the dimensions of a tax rate and easier to take to the data, unlike τ_t which, like the wage, is a rate per unit of time. A first order Taylor expansion of the righthand side of equation 37 around a point where $\tau_t' = \tau'$ gives a linear relationship exists between $\frac{A_{t+1}}{A_t}$ and τ_t':

$$d \ln A_{t+1} = b_0 + b_1 \tau_t' + \varepsilon_{A,t} \tag{38}$$

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.[59] Note that this relationship came out of the first order condition for z_t.Equation 38 drives the behaviour of the model in simulations.

Substituting into 37 using 31 reveals a relationship between z_t and τ_t'. Define $\frac{\partial z_t}{\partial \tau_t'} \equiv c_1$, assumed constant. The total derivative of the time endowment (4) gives $dx_t = -dN_t - dz_t$, and hence $\frac{dx_t}{x_t} = \frac{-dN_t - dz_t}{x_t}$. Assuming that $\bar{N} \approx \bar{x} \approx \frac{1}{2}$ in some initial steady state with approximately no z implies

$$\frac{dx_t}{\bar{x}} = d \ln x_t \approx -d \ln N_t - \frac{dz_t}{\bar{N}} = -d \ln N_t - 2dz_t \tag{39a}$$

Substituting into the loglinearised intratemporal condition (equation 7) for $\ln w_t$ from 27 and using 39a, we obtain (after integrating):

$$\ln \tilde{w}_t = const_4 + \rho_2 \ln N_t + \rho_1 \ln C_t + \left[\frac{1-\omega}{\omega}\right]^\sigma \ln Q_t + \rho_2 2 c_1 \tau_t' + e_{w,t} \tag{40}$$

[56] $\frac{dA_{t+i}}{dA_{t+i-1}} = \frac{A_{t+i}}{A_{t+i-1}}$. Hence for $i \geq 1$,

$$\frac{d\ A_{t+i}}{dz_t} = \frac{d\ A_{t+i}}{dA_{t+i-1}} . \frac{d\ A_{t+i-1}}{dA_{t+i-2}} ..... \frac{d\ A_{t+2}}{dA_{t+1}} . \frac{d\ A_{t+1}}{dz_t} = A_{t+i} \frac{A_t}{A_{t+1}} a_1 \tag{34}$$

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 via productivity (holding inputs fixed), and will also induce the firm to hire more capital to exploit its higher marginal product (similarly for labour). I assume the effect of dz_t on the future dividend ($d_{t+i} = \pi_{t+i}$) is simply its direct effect through higher TFP, as any effects on the firm's input demands are second order and can be ignored. Therefore the expected change in the dividend stream is based on forecasts for choice variables (set on other first order conditions) that are assumed 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.

[57] 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.

[58] Although in balanced growth $\frac{C}{Y}$ is constant, in the presence of shocks it moves in an unpredictable way.

[59] Other terms in the expansion are treated as part of the error term.

where

$$e_{w,t} = -\ln \gamma_t + \ln \xi_t + \frac{1}{\rho}\left[\frac{1-\omega}{\omega}\right]^{\sigma} \ln \varsigma_t \tag{41}$$

τ'_t penalises z_t, so $c_1 < 0$, hence $\frac{d \ln \tilde{w}_t}{d\tau'_t} < 0$ or $\frac{d \ln N_t}{d\tau'_t} > 0$, since equation 40 is the labour supply condition rearranged; the worker responds to a higher penalty on z_t by raising labour time.[60]

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.

$$Y_t = C_t + I_t + G_t + EX_t - IM_t \tag{42}$$

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 balance of payments identity is restricted so 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.

$$r^f_T b^f_T = -\left(\frac{p^d_T . EX_T}{Q_T} - IM_T\right) \tag{43}$$

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, $\Delta \hat{b}^f_{t+1} = 0$ as $t \to \infty$, where $\hat{b}^f_{t+1} = \frac{b^f_{t+1}}{Y_{t+1}}$. This implies that the growth rate of debt equals the growth rate of real gdp (g_Y).

A.6. The Log-Linearised System

The linearised system solved numerically is given below. All variables are in natural logs, except where variables are already expressed in percentages (e.g. $\hat{b}^f_t$, 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.

[60] Substituting into equation (37) from (31), rearranging for z_t, then taking the derivative with respect to τ'_t, we find $c_1 = -\frac{\frac{\beta\rho_\gamma}{1-\beta\rho_\gamma}\frac{Y_t}{C^{\rho_1}_t}}{\frac{w_t}{C^{\rho_1}_t}(1+\tau'_t)^2}$; we could potentially calibrate c_1 from this, taking appropriate values for righthand side variables. However there is flexibility around what values are 'appropriate'. The same is true for b_1.

$$
\begin{aligned}
r_t &= \rho_1 \left(E_t \ln C_{t+1} - \ln C_t\right) + e_{r,t} && (44)\\
\ln Y_t &= \alpha \ln N_t + (1-\alpha) \ln K_t + \ln A_t && (45)\\
\ln N_t &= \ln Y_t - \tilde{w}_t + e_{n,t} && (46)\\
\ln K_t &= \zeta_1 \ln K_{t-1} + \zeta_2 \ln K_{t+1} + \zeta_3 \ln Y_t - \zeta_4 r_t + e_{k,t} && (47)\\
\ln C_t &= \frac{\bar{Y}}{\bar{C}} \ln Y_t - \frac{EX}{\bar{C}} \ln EX_t + \frac{IM}{\bar{C}} \ln IM_t - \frac{\bar{K}}{\bar{C}} \ln K_t + && (48)\\
& \quad (1-\delta-\gamma_k) \frac{\bar{K}}{\bar{C}} \ln K_{t-1} - \frac{\bar{G}}{\bar{C}} \ln G_t \\
\ln \tilde{w}_t &= \rho_2 \ln N_t + \rho_1 \ln C_t + \left[\frac{1-\omega}{\omega}\right]^{\sigma} \ln Q_t + \tilde{\psi}_1 \tau'_t + e_{wh,t} && (49)\\
\ln w_t &= \ln \tilde{w}_t - \left[\frac{1-\omega}{\omega}\right]^{\sigma} \ln Q_t + e_{w,t} && (50)\\
\ln EX_t &= \ln C^*_t + \sigma^F \frac{1}{\omega} \ln Q_t + e_{X,t} && (51)\\
\ln IM_t &= \ln C_t - \sigma \ln Q_t + e_{M,t} && (52)\\
\ln Q_t &= E_t \ln Q_{t+1} + r^f_t - r_t && (53)\\
\Delta \hat{b}^f_{t+1} &= r^f_t . \hat{b}^f_t + \left(\frac{1}{1+g}\right) \begin{pmatrix} \frac{EX}{\bar{Y}} \ln EX_t - \frac{EX}{\bar{Y}} \frac{1}{\omega} \ln Q_t \\ -\frac{IM}{\bar{Y}} \ln IM_t \end{pmatrix} && (54)\\
\ln A_t &= \ln A_{t-1} + b_1 \tau'_{t-1} + e_{A,t} && (55)\\
\ln C^*_t &= \rho_{C^*} \ln C^*_{t-1} + \eta_{C^*,t} && (56)\\
\ln G_t &= \rho_G \ln G_{t-1} + \eta_{G,t} && (57)\\
r^f_t &= \rho_{rf} r^f_{t-1} + \eta_{rf,t} && (58)\\
\tau'_t &= \rho_\tau \tau'_{t-1} + \eta_{\tau,t} && (59)
\end{aligned}
$$

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 the producer unit cost of labour $\tilde{w}_t$, see equations 27 and 41).[61] 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; i denotes the variable on which the equation is normalised.

A.6.1. Stochastic processes

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

$$e_{i,t} = a_i + b_i t + \rho_i e_{i,t-1} + \eta_{i,t} \tag{60}$$

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

$$
\begin{aligned}
\hat{e}_{i,t} &= \rho_i \hat{e}_{i,t-1} + \eta_{i,t} && (61)\\
\hat{e}_{i,t} &= e_{i,t} - \hat{a}_i - \hat{b}_i t && (62)
\end{aligned}
$$

The innovations $\eta_{i,t}$ are approximated by the fitted residuals from estimation of equation 61, $\hat{\eta}_{i,t}$. These are then used to bootstrap the model. The bootstrapping methodology is discussed in Section

[61] Where equations are not straightforwardly linear in logs, they are linearised around sample mean values, denoted by overbar. 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. 16, allowing the approximation: $\ln p^d_t - \ln Q_t = -(\frac{1-\omega}{\omega} + 1) \ln Q_t = -\frac{1}{\omega} \ln Q_t$.

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 38 (Appendix A).

$$\ln A_t = d + \ln A_{t-1} + b_1 \tau_{t-1} + e_{A,t} \tag{63}$$

$$e_{A,t} = \rho_A e_{A,t-1} + \eta_{A,t} \tag{64}$$

A.7. Solution

The model 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 ensure that the simulated paths for the endogenous variables converge to a long run level consistent with the model's own long run implications. Since the model 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).

APPENDIX 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.

Notes to Table 7:

[1] Working population is total claimant count plus total workforce jobs.

[2] Nominal NFA is accumulated current account surpluses (£m), taking the Balance of Payments international investment position as a starting point.

[3] AEI for whole economy including bonuses.

[4] Weights as P_F. Germany proxies EU.

[5] BERD is Business Enterprise R&D.

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.24	(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. 19	(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 7
Data Description

B.1. Data for Policy Indicator

UK data on τ_t' reflects 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 subsection 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 for 2000-2009.

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)."[62] 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.[63] 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.

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).[64] 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.[65] The correlations in the data bear this out (Table 8).

The resulting quarterly series for CCB and MCH incorporate information from the unionisation rate.[66] These interpolated series are inverted so as to represent a penalty rate, where a higher value indicates a more hostile business environment.[67] They are plotted below in Figures 7 and 8 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 4), labelled the 'Labour Market Regulation' indicator (LMR).[68] 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 9).[69] This suggests that the LMR indicator may not be a bad proxy for

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

[63] "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).

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

[65] 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).

[66] 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.

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

[68] A fuller measure of labour market regulatory friction would reflect 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 EPL measures 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.

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

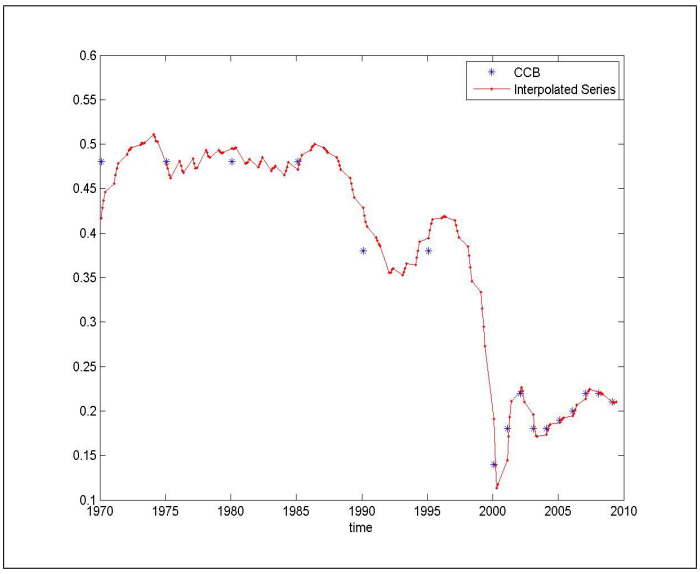

FIG. 7 Inverted Fraser Institute Centralized Collective Bargaining (CCB) Score; Original Points and Interpolated Series.

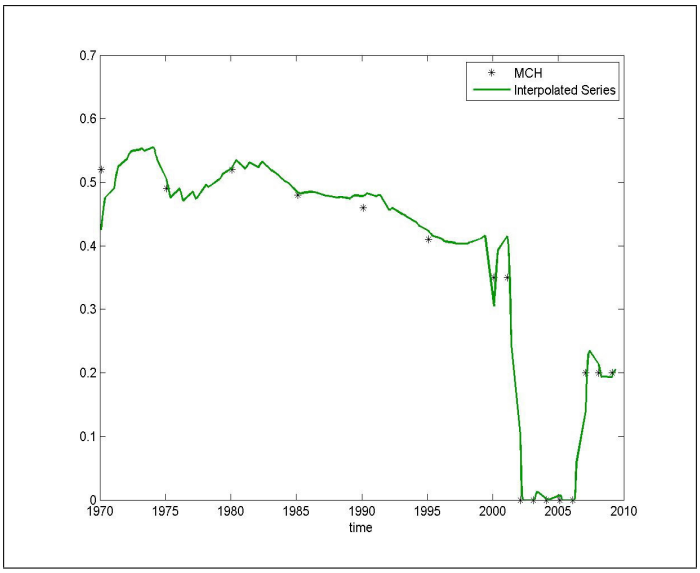

FIG. 8 Inverted Fraser Institute Marginal Cost of Hiring Score; Original Points and Interpolated Series.

	CCB	**MCH**
MCH	0.797	1.000
TUM (inv)	0.899	0.764

TABLE 8
Correlations: Fraser Institute Labour Market Indicators CCB and MCH, and Trade Union Membership rate, inverted (TUM inv).

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

TABLE 9
Correlations: OECD Product Market Regulation Indicator (Network Industries), Fraser Institute Indicators (CCB and MCH), and Trade Union Membership

product market entry regulation in the UK.

The second part of the index for τ_t' reflects the tax environment faced by the would-be entrepreneur. The top marginal income tax rate is used for $\tau(1)$ (see main text). See Appendix D for robustness checks on alternate indices.

APPENDIX 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

$$A(L)y_t = BE_t y_{t+1} + C(L)x_t + D(L)e_t \tag{65}$$

$$\Delta x_t = a(L)\Delta x_{t-1} + d + b(L)z_{t-1} + c(L)\epsilon_t \tag{66}$$

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

$$y_t = G(L)y_{t-1} + H(L)x_t + f + M(L)e_t + N(L)\epsilon_t \tag{67}$$

where f is a vector of constants. Under the null hypothesis of the model, the equilbrium solution for

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

TABLE 10
Correlation Coefficients for Tax and Regulatory Components of Composite Index. Correlations are with the inverted, interpolated Fraser Index scores for CCB and MCH (higher score indicates higher regulation).

the endogenous variables is the set of cointegrating relationships (where Π is p x p)[70]:

$$y_t = [I - G(1)]^{-1}[H(1)x_t + f] \quad (68)$$
$$= \Pi x_t + g \quad (69)$$

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

$$y_t - (\Pi x_t + g) = \eta_t \quad (70)$$

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.

$$\bar{y}_t = \Pi \bar{x}_t + g \quad (71)$$
$$\bar{x}_t = [1 - a(1)]^{-1}[dt + c(1)\xi_t] \quad (72)$$
$$\xi_t = \Sigma_{s=0}^{t-1} \varepsilon_{t-s} \quad (73)$$

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

$$\Delta y_t = -[I - G(1)](y_{t-1} - \Pi x_{t-1}) + P(L)\Delta y_{t-1} + Q(L)\Delta x_t + f + \omega_t \quad (74)$$
$$\omega_t = M(L)e_t + N(L)\varepsilon_t \quad (75)$$

which can be approximated as

$$\Delta y_t = -K[y_{t-1} - \Pi x_{t-1}] + R(L)\Delta y_{t-1} + S(L)\Delta x_t + h + \zeta_t \quad (76)$$

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

$$\Delta y_t = -K[(y_{t-1} - \bar{y}_{t-1}) - \Pi(x_{t-1} - \bar{x}_{t-1})] + R(L)\Delta y_{t-1} + S(L)\Delta x_t + m + \zeta_t \quad (77)$$

considering ζ_t to be i.i.d. with zero mean. Rewriting equation 76 as a levels VARX(1) we get

$$y_t = [I - K]y_{t-1} + K\Pi x_{t-1} + n + \phi t + q_t \quad (78)$$

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.

APPENDIX D: ADDITIONAL TESTS

D.1. Indirect Inference Test Results: Alternative Auxiliary Models

Table 11 reports the percentile of the Wald distribution in which the test statistic falls, for various auxiliary models - all VARX(1) but with additional endogenous variables. These constitute more stringent tests as the model must be well specified in more dimensions (in some cases for variables not usually well explained by workhorse RBC models of this type, e.g. consumption, wages). Any percentile below 95 is a non-rejection given the 5% test size. Every auxiliary model reported includes $\tau_{t-1}$and b_{t-1}^f (lagged policy and net foreign assets) as exogenous variables. Trend and constant terms are also included in every VECM but excluded from the Wald test. All tests are carried out given the estimated structural coefficients discovered in Section 5. These results indicate that (in addition

[70] 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.

Auxiliary model	(1)	(2)	(3)	(4)	(5)
Endogenous	Y, A	Y, A, r	Y, A, Q	Y, A, K	Y, A, N
Wald percentile	72.23	82.37	90.16	92.93	94.41
Auxiliary model	(6)	(7)	(8)	(9)	(10)
Endogenous	Y, A, C	Y, A, N, C	Y, A, r, Q	Y, A, r, K	Y, A, r, N
Wald percentile	95.05	94.04	89.47	94.80	94.92
Auxiliary model	(11)	(12)	(13)	(14)	(15)
Endogenous	Y, A, X	Y, A, M	Y, A, M, X	Y, A, K, C	Y, A, Q, N
Wald percentile	96.12	86.40	98.71	94.26	95.12
Auxiliary model	(16)	(17)	(18)	(19)	(20)
Endogenous	Y, A, M, Q	Y,A,M,Q,r	Y, A, C, M	Y, A, w	Y, A, $\tilde{w}$
Wald percentile	93.38	95.25	99.1	97.28	98.60

TABLE 11
Indirect Inference test results for auxiliary VARX(1),various endogenous variables

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

TABLE 12
Key to Policy Variables

to output and productivity) the model performs particularly well on real interest rates, real exchange rates and import demand which are important open economy features of the UK.

D.2. Robustness Tests

Results are checked for three measures of τ' described earlier (Table 12). The Wald-minimising coefficients found for the $\tau(1)$ series were tested on the baseline auxiliary model using $\tau(2)$, the combination of the LMR indicator with the tax rate on corporate profits (small business rate). Given these coefficients (Table 4), the test statistic islarger for $\tau(2)$ than for $\tau(1)$ but still well inside the non-rejection region (Wald percentile is roughly 85). The same tests were carried out for $\tau(3)$. For the coefficients in Table 4 the model with $\tau(3)$ is also not rejected at 5% significance, (Wald percentile 94.41).

These robustness checks show that the non-rejection of the model is not overly sensitive to the weighting/composition of the policy index; the conclusions do not stand or fall on one component of the business environment versus another. The model passes the test for a policy driver reflecting labour market flexibility alone, and when tax indicators are added. However, the inclusion of the top marginal income tax rate with its large step changes yields a lower Wald percentile for the model and this policy component seems to have had important effects.[71]

[71] 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).