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Structural Reforms, Innovation and Economic Growth

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Abstract

This paper constructs a growth model of the distance from the world technology frontier to argue that firms' incentives to innovate and the government's decision on implementing reforms can be mutually reinforcing. This complementarity may, however, result in a country falling into a self-perpetuating low productivity trap. Certain types of structural change, initiated either by the private sector or by the government, can help the country to escape from this trap.

Keywords: Economic Growth, Economic Reform, Productivity Gap

JEL: O11, O43

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1 Introduction

It has long been argued that one of the most serious problems facing the Japanese economy is its declining potential growth relative to other developed countries, and various kinds of structural reforms to promote economic growth have been proposed.[1] Looking back over the longer run, Japan experienced rapid economic growth between the 1950s and early 1970s, followed by a period of more rapid growth than the US that lasted until the 1980s. Since the late 1990s, however, its productivity has lagged behind that of the United States. This phenomenon can be observed in more detail in Figure 1, which shows labour productivity growth in selected OECD countries against their distance from the world technology frontier between 1960 and 2010. The United States is taken as the world technology frontier, and each country's distance from the frontier is defined as the difference between its labour productivity and that of the United States. Figure 1 illustrates how countries tend to move towards the world technology frontier, while their labour productivity growth rates decrease as they approach it.[2] The figure also reveals that Japan's distance from the frontier has widened again in recent years. This implies that Japan has failed to catch up with the United States in terms of labour productivity level. What explains this stagnation in Japan's productivity level relative to that of the United States?

This paper argues that Japan may have been suffering from a vicious cycle in which the government's lacklustre economic reforms and firms' reluctance to innovate are negatively reinforcing. We construct a model of Schumpeterian growth based on Acemoglu et al. (2006) in which the distance of a country's technology level from the world technology frontier affects not only firms' technology choice but also the government's incentive to promote economic reforms. In our model, firms

[1] See, for example, Nakaso (2016) who discusses structural reforms from a policymaker's point of view. He draws out the policy implications of low rates of economic growth, arguing that structural reforms are needed to increase the potential growth rate.

[2] The growth-maximising path in Figure 1 is defined in Section 3.2.

have a choice between catching up with the existing technology and innovating new technology. As in Acemoglu et al. (2006), innovation becomes more profitable to firms than catch up only when the distance from the frontier is small enough. Importantly, firms' technology choice also depends on whether the government implements reforms in labour and product markets. The government's incentive to implement economic reforms in turn depends on the firms' technology choice because the benefits from reforms are sensitive to the size of the economy. In other words, the model is set up so that firms' decision to innovate and the government's decision to implement economic reforms are complements.

It is shown that, at intermediate distances from the world technology frontier, there are multiple equilibria. In one equilibrium, firms innovate new technology and the government implements economic reforms. The productivity level of the economy converges to that of the frontier country. In the other equilibrium, firms remain mired in the catch-up regime and the government does not conduct economic reforms. In this equilibrium, the economy can end up in a non-convergence trap in which the country's productivity level never catches up with that at the world technology frontier.

We calibrate the model to the OECD countries including Japan to find that Japan is indeed in the region of multiple equilibria; it may, therefore, be trapped in a bad equilibrium. The government's lacklustre efforts to promote structural reforms discourage firms from switching from catch up to innovation, and their productivity remains lagging behind that of the United States. Lower firm productivity in turn reduces the size of the economy and hence the benefits from structural reforms, curbing the government's incentive to carry out reforms in the face of the political cost of implementing them.

Finally, we demonstrate the significant benefits that may accrue if certain types of structural change are implemented by either the private sector or the government. Where such structural changes stimulate the economy, the benefits of even politically challenging economic reforms can become large enough to outweigh their costs, eliminating the vicious cycle and creating a virtuous one.

Related Literature There is vast literature on Japan's economic stagnation since the 1990s. A pioneering work by Hayashi and Prescott (2002) argues that declining TFP growth is the most important factor in explaining this stagnation. Following Hayashi and Prescott (2002), many papers investigate Japan's TFP growth. Kameda (2009) provides a survey on Japan's productivity.[3] Blomstrom et al. (2003) raise several challenges confronting policymakers and the private sector that may explain the productivity stagnation in Japan.

As for the private sector, Fukao and Kwon (2006) argue that there was limited reallocation of resources from less efficient to more efficient firms in the 1990s.[4] Caballero et al. (2008) emphasise the role of credit misallocation in firms' choices over employment and investment. They focus on misdirected bank lending to unprofitable borrowers which they call "zombie firms." In related work, Nakakuki et al. (2004) address distortions in factor markets, while Sekine et al. (2003) and Akashi et al. (2008) discuss the misallocation of credit. Muto et al. (2016) suggest that inefficient allocation in factor markets was rooted in damaged balance sheets of firms and financial intermediaries after the bubble burst in the early 1990s. Kaihatsu and Kurozumi (2014) argue that a tightening of firms' financing in the early 1990s reduced R&D investment and induced misallocation of resources. Ikeda and Kurozumi (2014), meanwhile, construct an endogenous growth model which they use to argue that the financial crisis of 1997 lowered TFP growth due to firms' reduced R&D expenditure. Their model suggests that the adverse effects of financial shocks are long-lasting.

Other papers emphasise the role of economic policy in explaining low produc-

[3] Kameda (2009) argues that the growth rate of Japan's TFP increased in the 2000s. Kawamoto (2005) and Fueki and Kawamoto (2009) also discuss measurements of TFP in Japan.

[4] See also Nishimura et al. (2005), who find that during the banking-crisis period of 1996–1997 there was exit by efficient firms while inefficient firms survived.

tivity. Fukao et al. (2009) argue that low productivity in the Japanese services sector is partly due to excessive regulations and lack of competition in the public service sector.[5] Hoshi and Kashyap (2012) and Hoshi and Haidar (2015) argue that restoring vigour to the Japanese economy requires economic reform, and they list the kinds of reforms needed. Compared with the existing literature, our paper emphasises the interaction between the government's incentive to promote economic reform and that of the private sector to innovate. The major implication drawn is that the private sector and the government must move together to escape from the vicious cycle.

Other literature relevant to our study includes that on the productivity gap between the United States and other advanced countries, such as Aghion and Howitt (2006), Jones (2015) and Parente and Prescott (1994). From a longer perspective, Hayashi and Prescott (2008) argue that barriers to labour mobility between the agricultural and manufacturing sectors explain about a quarter of the gap in per capita output between Japan and the United States in the pre-war period. Ikeda and Morita (2016) argue that low capacity to absorb technology, economic and political frictions with the outside world, and a lack of competition acted as barriers to technology adoption in Japan during that period. In particular, our paper is motivated by Acemoglu et al. (2006) who construct a model in which technological progress in a country comes from innovation by domestic firms and adoption of technologies from the world frontier. Using the model, they explain why policies discouraging innovation may impede the economy's progress toward the frontier. We modify the model by Acemoglu et al. (2006) by explicitly introducing the government's objective function, and calibrate it based on Japanese data. Our contribution to this strand of literature is twofold. First, we find that our model successfully tracks the economic growth paths of Japan and other developed countries in the last few decades.

[5]Their paper focuses on the contributions of ICT to productivity and resource reallocation. They find that the reallocation of capital resources is weak and consequently call for policies that promote capital reallocation.

Specifically, the model captures well Japan's productivity stagnation since the late 1990s. Second, we explicitly analyse the complementarity between firms' technology choice and the incentive of the government to implement economic reform.

Finally, the declining working population and societal ageing have also been considered as key contributing factors behind Japan's stagnant economic growth. From a policymaker's perspective, Shirakawa (2012a,b) discusses how demographic factors interact with productivity growth. Sakura et al. (2012) provide a survey on demography and economic growth in Japan.[6] The implications of a declining labour force for economic reform and productivity growth, in the context of our own model, are discussed in Section 7.2.

The rest of the paper is structured as follows. Section 2 lays out the model. Sections 3 and 4 characterise the equilibria of the model economy. Section 5 explains the model calibration. In Section 6 we analyse the multiple equilibria, and demonstrate the presence of a vicious cycle. In Section 7 we discuss several options for escape from the vicious cycle.

2 Model

This section lays out the model. Our model is based on that of Acemoglu et al. (2006), which is itself a variant of the Schumpeterian growth model where technological progress is represented by improvements in the quality of differentiated intermediate goods. There are five types of agents: final goods producers; intermediate goods producers; R&D firms; the representative household; and the government. Final goods producers use labour and intermediate goods to produce final goods. There is a continuum of differentiated intermediate goods indexed by $v \in [0, 1]$. Intermediate goods producer v produces intermediate good v using the final good

[6] Katagiri (2012) provides a theoretical argument for how changes in demand structure due to ageing can combine with labour market frictions to lower aggregate productivity. Muto et al. (2016) construct an overlapping generations model to investigate the macroeconomic impacts of ageing in Japan. Ikeda and Saito (2014) investigate the implications of ageing for real interest rates.

as an input. R&D firms hire labour to improve the quality of intermediate goods. The representative household consumes final goods and supplies labour. Finally, the government decides whether or not to implement reform.

2.1 Final good producers

The final good producers produce final goods using labour and intermediate goods. Their production function is given by

$$Y_t = \frac{1}{1-\sigma}(N_t)^\sigma \left[\int_0^1 (A_t^v)^\sigma (X_t^v)^{1-\sigma} dv\right], \quad 0 < \sigma < 1, \tag{1}$$

where Y_t denotes output of final goods, while N_t and X_t^v denote, respectively, the inputs of labour used in the production of final goods and intermediate good v. σ is the parameter which reflects the labour share in final good production. In what follows, we refer to the final good labour input N_t as "final good labour." A_t^v represents the productivity of intermediate good v available at time t. The final goods market is competitive. Final goods producers maximise their profit π_t:

$$\pi_t = Y_t - (1+\tau_p)\, W_{N,t} N_t - \int_0^1 P_t^v X_t^v dv, \tag{2}$$

where $W_{N,t}$ and P_t^v denote, respectively, the wage for final good labour and the price of intermediate good v.

Here τ_p represents labour market distortion, referred to as the "labour wedge"(see, for example, Shimer (2009) and Karabarbounis (2014)). It captures not only the distortions caused by labour income taxation, but also other distortions and frictions in the labour market. In equilibrium, it represents the wedge between the marginal rate of substitution of consumption for leisure and the marginal product of labour.

Recent studies of Japan's labour market argue that the life-time employment and seniority-based wages common in Japan for decades have been generating distortions in the labour market. Fukao et al. (2006) and Naganuma and Nishioka (2014) argue that the life-cycle wage profiles of workers in Japan do not match their marginal product of labour, a phenomenon that accords well with the mechanism explored by Lazear (1979) for long-run retention of workers.[7]

Under the seniority-based wage system, older (young) workers receive higher (lower) wages than their marginal product of labour. This can be sustainable when the demographic structure of the workforce is stable or the growth rate of the working population is positive. However, with an ageing workforce and shrinking younger cohort, the seniority-based wage system has placed a corresponding burden on firms which pay wages to their senior workers that exceed their productivity. Furthermore, Genda et al. (2010) document how, as life-time employment became a common practice in Japan, there emerged a "social norm" that firms should be responsible for their workers' job security. They argue that this social norm has since been strengthened by case law that has made firing workers extremely difficult, and that it has also been responsible for the underdevelopment of secondary job markets for mid-career workers. The implication of the existing literature is, therefore, that τ_p includes distortions due to both government policy and private-sector employment practices.[8] Although, in the initial sections of this paper, we begin by considering a setting where τ_p is determined by government policy, emphasising this through the addition of the subscript "p", we later extend the discussion, in Section 7.1, to the case where the private sector can also affect the labour wedge.

2.2 Intermediate goods producers

Intermediate goods producer v produces intermediate good v. Following Acemoglu et al. (2006), we assume that, for each intermediate good v at time t, one production site, called the "leading firm" has access to the most productive technology A_t^v. The

[7] Lazear (1979) presents a model where the discrepancy between the wage profile and the marginal product of labour is used as a contractual device to retain workers over the longer term.

[8] While case law itself is not established by the government, it may be firmly linked to the government policy. For example, the government takes account of case law in conducting policies related to labour market, such as taxation and social insurance system.

leading firm can transform one unit of final good into one unit of intermediate good with productivity A_t^v. The leading firm faces competition from "fringe firms". Fringe firms can steal the leading firm's technology to produce an identical intermediate good, but production costs them $\chi^v > 1$ units of final good.

Facing this competition, the leading firm cannot charge a price that exceeds χ^v in equilibrium, because otherwise the competitive fringe could profitably enter the market. The price of each intermediate good is thus given by its limit-price

$$P_t^v = \chi^v. \tag{3}$$

Since the final goods sector is competitive, the demand for intermediate good v satisfies

$$X_t^v = (\chi^v)^{-1/\sigma} A_t^v N_t. \tag{4}$$

Then, the profit of firm v, π_t^v, is given by

$$\pi_t^v = (\chi^v - 1) X_t^v = \delta^v A_t^v N_t, \tag{5}$$

where

$$\delta^v \equiv (\chi^v - 1)(\chi^v)^{-1/\sigma}. \tag{6}$$

Our interpretation of χ^v is that it represents the degree of difficulty in stealing and replicating the production technology. In a later section, we make what we believe to be a natural assumption that χ^v is higher for goods that require innovations to raise A_t^v.

2.3 R&D firms

R&D firms are engaged in R&D activities. They hire labour to improve the quality (A_t^v) of intermediate goods. The improvement in the quality of the intermediate goods represents that in productivity and hence technology. We assume that the

R&D firms can make use of the stock of knowledge at the world technology frontier as well as that of the domestic economy. Let $\bar{A}_t$ denote the world technology frontier. Its growth rate is assumed to be given by g:

$$\bar{A}_t = (1+g)\bar{A}_{t-1}. \tag{7}$$

Let

$$A_t \equiv \int_0^1 A_t^v dv \tag{8}$$

be the average quality of intermediate goods produced in the economy. The technology of the R&D firm working on the quality of intermediate good v is given by

$$A_t^v = [\lambda^v U_t^v]^\alpha \left(\eta^v \bar{A}_{t-1} + \gamma^v A_{t-1}\right), \quad 0 < \alpha < 1, \tag{9}$$

where U_t^v is the labour used in R&D, and the parameter λ^v represents the efficiency of R&D activities. α is the parameter which controls the effectiveness of labour input. In what follows, we call U_t^v "R&D labour." Terms $\eta^v \bar{A}_{t-1}$ and $\gamma^v A_{t-1}$ represent, respectively, the spillover effects from the world technology frontier and from the average technology level of the country.

Following Acemoglu et al. (2006), we assume that R&D firms have a choice of two R&D strategies: "catch-up" or "innovation."[9] If a firm chooses the catch-up strategy,

$$\eta^v = \eta_c, \quad \gamma^v = \gamma_c. \tag{10}$$

If the firm instead chooses the innovation strategy,

$$\eta^v = \eta_i, \quad \gamma^v = \gamma_i. \tag{11}$$

[9] In Acemoglu et al. (2006), R&D types are modelled as entrepreneur types. They consider a situation in which firm owners choose entrepreneurs for their firms. Here different types of R&D firm are modelled in terms of technology choice.

We assume[10]

$$\eta_c > \eta_i \quad \text{and} \quad \gamma_c < \gamma_i. \tag{12}$$

This assumption means that, the R&D firms which choose the catch-up strategy enjoy greater spillovers from the existing frontier technology ($\bar{A}_{t-1}$). By contrast, those choosing to innovate gain a larger spillover effect from their own R&D activities (A_{t-1}). We also assume that the efficiency of R&D activities (λ^v) differs between the two strategies. Set $\lambda^v = \lambda_c$ if the R&D firm chooses the catch-up strategy, and $\lambda^v = \lambda_i$ if it chooses the innovation strategy. We impose an assumption that

$$\lambda_c > \lambda_i. \tag{13}$$

This assumption captures the fact that innovation is more difficult than catch up in the sense that innovation requires a larger labour input in order to raise productivity A_t^v.

Furthermore, as is discussed above, we assume that it is more difficult for fringe firms to copy innovative technology than catch-up technology. Setting the difficulty of imitation $\chi^v = \chi_c$ for R&D firms pursuing the catch-up strategy and $\chi^v = \chi_i$ for R&D firms choosing the innovation strategy, we assume

$$\chi_i > \chi_c. \tag{14}$$

This assumption implies that once a firm shifts to an innovation strategy it can enjoy a higher mark-up.

Finally, we assume that different R&D strategies involve different installation costs $\kappa^v \bar{A}_{t-1}$.[11] These costs represent the regulatory costs of starting up new types of business. Hoshi and Haidar (2015) investigate the various costs of starting new

[10] For normalisation we assume $\eta^v + \gamma^v = 1$.

[11] Here we normalise the cost by multiplying by $\bar{A}_{t-1}$ so that the cost remains non-negligible as the economy grows.

businesses in Japan in comparison with other OECD countries, concluding that many costs are higher in Japan. As they argue, these costs obviously depend on government policy. For example, certain kinds of deregulation (relaxing regulations on firm entry, for example) can change κ^v. Here, we assume that installing innovative technology is more costly than installing catch-up technology, which we believe is a natural assumption. Set $\kappa^v = \kappa_c$ if R&D firms choose the catch-up strategy and $\kappa^v = \kappa_i$ if they choose the innovation strategy. Let κ_p denote the cost of installing innovation technology. Again, we use the subscript "p" to emphasise the fact that the cost depends on government policy (dealt with in Section 2.5). Note that we normalise the cost of installing catch-up technology by setting it equal to zero. To summarise, κ^v is given by

$$\kappa^v = \begin{cases} \kappa_i = \kappa_p & \text{innovation,} \\ \kappa_c = 0 & \text{catch up.} \end{cases} \tag{15}$$

We assume that patent markets are competitive.[12] This implies that the price, Q_t^v, of the patent for the most up-to-date technology A_t^v for intermediate good v equals the profit of the firm that produces good v, net of installation cost ($\kappa^v \bar{A}_{t-1}$):

$$\begin{aligned} Q_t^v &= \pi_t^v - \kappa^v \bar{A}_{t-1} \\ &= \delta^v A_t^v N_t - \kappa^v \bar{A}_{t-1}. \end{aligned} \tag{16}$$

where δ^v is defined in equation (6). Therefore, the R&D firm which seeks to improve the production technology of intermediate good v (i.e. to raise productivity A_t^v) chooses its demand for R&D labour U_t^v and R&D strategy (either catch up or

[12] Since patent markets are competitive, it does not matter to the equilibrium analysis whether intermediate goods firms or R&D firms pay the installation cost κ. In our model we assume that the intermediate good firms pay this fixed cost. If we were to assume instead that R&D firms paid this cost, the price of the patent would be $\delta^v A_t^v N_t$ but the value of the R&D firm would remain the same as in equation (17).

innovation) in order to maximise the following profit function:

$$\begin{aligned} V_t^v &= Q_t^v - W_{U,t} U_t^v \\ &= \delta^v A_t^v N_t - \kappa^v \bar{A}_{t-1} - W_{U,t} U_t^v. \end{aligned} \tag{17}$$

subject to its R&D production function (9). Here $W_{U,t}$ is the wage of R&D labour, and κ^v is given by equation (15).

2.4 Household

The representative household consumes final goods (C_t) and supplies the two types of labour (U_t and N_t) to maximise utility:

$$\sum_{t=0}^{\infty} \beta^t \left[\log(C_t) - \phi_U U_t - \phi_N N_t\right], \quad 0 < \beta < 1, \tag{18}$$

where β is the household's discount factor. It is subject to the standard intertemporal budget constraint. ϕ_N and ϕ_U are the parameters controlling, respectively, disutility of final good labour and of R&D labour. Since the decision problem of the household is fairly standard, we present only the labour supply decisions which are important for our analysis. The supply decisions of R&D and final good labour are respectively given by

$$\frac{1}{C_t} W_{U,t} = \phi_U, \tag{19}$$

$$\frac{1}{C_t} W_{N,t} = \phi_N. \tag{20}$$

2.5 Government

The government decides whether or not to implement economic reform. We consider reforms in both labour and product markets. The labour market reform in our model is represented by a reduction in the labour wedge τ_p. As is discussed in Section 2.1, a part of the wedge is a result of government policy. This corresponds in reality to reforms such as relaxing legal restrictions on firing workers, and establishing institutional arrangements that make it easier for workers to change jobs.[13] The product market reform in our model is represented by a reduction in fixed cost κ_p. Hoshi and Haidar (2015) provide a detailed list of the many kinds of economic reform needed to improve the environment for starting up new businesses in Japan. Those major costs of doing businesses include costs of creating new firms, obtaining construction permits (for warehouses, for example), getting electricity, registering property, getting credit, protecting minority investors, paying taxes, trading across borders, enforcing contracts, resolving insolvency. We do not attempt to model the details of these reforms since that would be beyond the scope of the paper. Instead, we seek to capture all such product market reform through a simple reduction of the model's fixed installation or start-up cost. We assume to begin with that the government controls τ_p, and κ_p.

We assume that the government maximises a weighted sum of the discounted sum of future output and firms' current profit. The assumption that the government takes future output into account implies that the government may prefer a policy that achieves higher growth rates even if that policy reduces output temporarily. Inclusion of firms' profit into the government's objective function is a crude way of capturing the fact that some interest groups affect political decisions. It could reflect the private benefits that politicians receive from interest groups acting on behalf of firms. Let V_t denote the aggregate profit of R&D firms at time t:

$$V_t \equiv \int_0^1 V_t^v dv. \tag{21}$$

[13] The wedge τ_p may also include labour taxes. In what follows, we assume that the government transfers tax revenues in a lump sum manner to the representative household. As a result the government budget constraint and the associated household budget constraint do not play a significant role in the model. Therefore we do not write down details of those in the paper.

The objective of the government is given by:

$$\Gamma_t = \varphi \sum_{i=0}^{\infty} \beta^i Y_{t+i} + (1-\varphi) V_t - \omega_t \bar{A}_{t-1}, \quad 0 < \varphi < 1, \tag{22}$$

where φ is the weight on the final goods output, and $\omega_t \bar{A}_{t-1}$ represents the cost of implementing policy (to be discussed below). We multiply ω_t by $\bar{A}_{t-1}$ to ensure that the political cost remains non-negligible even as the economy grows. As the benchmark case we set $\varphi = 1$, which means the government is concerned solely with final goods output.[14] We consider a choice between two types of policy, "reform" or "status quo":

$$(\tau_p, \kappa_p) = \begin{cases} (\tau_r, \kappa_r) & \text{reform}, \\ (\tau_q, \kappa_q) & \text{status quo}, \end{cases}$$

where

$$\tau_r < \tau_q, \quad \kappa_r < \kappa_q.$$

Reforms are costly to the government. In reality, certain reforms require costly legal changes. Reforms may also incur political objections from interest groups who could be negatively affected. In order to capture these facts, we assume that the government has to pay a fixed cost to choose reform. This cost is represented by ω_t, which is given by

$$\omega_t = \begin{cases} \omega > 0 & \text{reform}, \\ 0 & \text{status quo}. \end{cases} \tag{23}$$

The government chooses either reform or status quo to maximise its objective function (22). We assume that in each period a political decision is made on economic reform under the expectation that this decision will not be overturned during the government's tenure and that the R&D firms' decisions on technology choice is kept constant. We believe this to be a plausible assumption about the behaviour of the

[14] We find that varying the value of φ between 0 and 1 does not substantially alter the results.

government when deciding on major political issues such as labour market reforms.[15] The sensitivity of the objective function (22) to the government's own policy will be discussed in later sections.

3 Symmetric Equilibrium Balanced Growth Path

In what follows we consider a symmetric equilibrium in which all R&D firms make identical decisions. Let subscript "s" denote the strategy choice of the R&D firm working to improve the productivity of intermediate good v:

$$s = \begin{cases} i & \text{innovation,} \\ c & \text{catch up.} \end{cases}$$

Next, as introduced in Section 2, let subscript "p" denote the policy choice of the government:

$$p = \begin{cases} r & \text{reform,} \\ q & \text{status quo.} \end{cases}$$

Since there is no capital in the model, the economy stays on the balanced growth path regardless of R&D firms' choice of R&D strategy ($s = i, c$) and government policy ($p = r, q$). On the balanced growth path, output (Y_t), consumption (C_t), intermediate goods investment (X_t), wages ($W_{N,t}$, $W_{U,t}$) grow at the same rate as A_t. Labour N_t and U_t are constant at all times. In what follows, for any variable z, let $z_t(S, p)$ denote the value of z at time t when R&D strategy taken by all of R&D firms is "S" and government policy is "p". (Note that $S = i, c$ and $p = r, q$.) If variable z is constant over time we suppress time subscript t. The balanced growth

[15] This assumption significantly simplifies the computation of equilibria. However, it is somewhat inconsistent with the notion of full rationality if governing politicians are infinitely long-lived. When making the current policy decision a fully rational politician will take into account the fact that the policy may be changed in the future, for example when the government changes hands.

path of the model economy is then given by:

$$N(S,p) = \frac{1}{1+\tau_p}\frac{\sigma\chi_S}{\phi_N(\chi_S+\sigma-1)} \tag{24}$$

$$U(S,p) = U(S) = \frac{\alpha(1-\sigma)(\chi_S-1)}{\phi_U(\chi_S+\sigma-1)} \tag{25}$$

$$y(S,p) \equiv \frac{Y_t(S,p)}{A_t(S,p)} = \frac{1}{1-\sigma}\chi_S^{\frac{\sigma-1}{\sigma}}N(S,p) \tag{26}$$

$$c(S,p) \equiv \frac{C_t(S,p)}{A_t(S,p)} = \frac{1}{1+\tau_p}\frac{\sigma}{\phi_N(1-\sigma)}\chi_S^{\frac{\sigma-1}{\sigma}} \tag{27}$$

$$x(S,p) \equiv \frac{X_t(S,p)}{A_t(S,p)} = \chi_S^{-\frac{1}{\sigma}}N(S,p) \tag{28}$$

$$w_N(S,p) \equiv \frac{W_{N,t}(S,p)}{A_t(S,p)} = \frac{1}{1+\tau_p}\frac{\sigma}{1-\sigma}\chi_S^{\frac{\sigma-1}{\sigma}} \tag{29}$$

$$w_U(S,p) \equiv \frac{W_{U,t}(S,p)}{A_t(S,p)} = \frac{1}{1+\tau_p}\frac{\phi_U}{\phi_N}\frac{\sigma}{1-\sigma}\chi_S^{\frac{\sigma-1}{\sigma}} \tag{30}$$

On the balanced growth path, $A_t(S,p)$ evolves according to

$$A_t(S,p) = A_t(S) = [\lambda_S U(S)]^\alpha \left(\eta_S \bar{A}_{t-1} + \gamma_S A_{t-1}\right). \tag{31}$$

where A_{t-1} is defined by equation (8). Note that R&D labour U does not depend on policy choice (equation (25)).

For the subsequent analysis it is useful to see how the equilibrium depends on the choice of the government and that of the R&D firms. The labour market wedge τ_p affects equilibrium final good labour negatively; it reduces aggregate output and consumption. The installation cost κ_p does not appear in equations (24) to (30), but it affects R&D firms' R&D strategy choice, which is to be analysed in detail in Section 4. Parameter χ_S has two offsetting effects. On the one hand, a higher χ_S implies that intermediate good firms can charge higher prices. This reduces output $y(S,p)$ and final goods employment $N(S,p)$. On the other hand, a higher χ_S means more profit for the intermediate good firms. This increases the price of patents, raising R&D investment (an increase in $U(S)$) and hence productivity A_t.

3.1 R&D Strategy Choice and the Non-Convergence Trap

This model seeks to describe the equilibria that result from the interaction between R&D strategy and the policy choices. Before characterising the equilibria of the economy, however, it is worth seeing how the model behaves under the two R&D strategy choices: (i) the innovation strategy; and (ii) the catch-up strategy. For the purposes of this subsection, let us assume the government chooses reform. Whether or not the government indeed chooses reform and whether the R&D firms choose the innovation or catch-up strategy in equilibrium will be analysed in Sections 4 through 6. For convenience, let

$$a_t(S) \equiv \frac{A_t(S)}{\bar{A}_t} \tag{32}$$

represent the "distance to the world technology frontier" at time t when R&D firms choose the strategy S, where $S = (i, c)$. Likewise, we denote the distance from the frontier at time t, considered independently of the R&D strategy choice, by

$$a_t \equiv \frac{A_t}{\bar{A}_t}. \tag{33}$$

Suppose that the R&D firms choose innovation. In this case, the technology level and labour input in the R&D firms become

$$A_t(i) = [\lambda_i U(i)]^{\alpha} \left(\eta_i \bar{A}_{t-1} + \gamma_i A_{t-1}\right), \tag{34}$$

$$U(i) = \frac{\alpha(1-\sigma)(\chi_i - 1)}{\phi_U(\chi_i + \sigma - 1)}. \tag{35}$$

Equation (34) can be further arranged as

$$a_t(i) = \frac{1}{1+g} [\lambda_i U(i)]^{\alpha} (\eta_i + \gamma_i a_{t-1}). \tag{36}$$

Now consider the steady state of equation (36). The steady state value, a_i, is given by[16]

$$a_i = \frac{\frac{1}{1+g}(\lambda_i U(i))^{\alpha}\eta_i}{1 - \frac{1}{1+g}(\lambda_i U(i))^{\alpha}\gamma_i}. \tag{37}$$

Here we normalise λ_i such that the steady state value of a_i equals to 1.[17] Inspection of difference equation (36) reveals that the economy converges monotonically to the world technology frontier.

Next, suppose instead that the R&D firms choose the catch-up strategy. In this case, the evolution of the distance from the frontier is given by

$$a_t(c) = \frac{1}{1+g}\left[\lambda_c U(c)\right]^{\alpha}\left(\eta_c + \gamma_c a_{t-1}\right), \tag{39}$$

$$U(c) = \frac{\alpha(1-\sigma)(\chi_c - 1)}{\phi_U(\chi_c + \sigma - 1)}. \tag{40}$$

The steady state value of $a_t(c)$ is given by[18]

$$a_c = \frac{\frac{1}{1+g}(\lambda_c U(c))^{\alpha}\eta_c}{1 - \frac{1}{1+g}(\lambda_c U(c))^{\alpha}\gamma_c}. \tag{41}$$

Because of assumptions (12) and (14), if λ_c is not too large[19], we obtain

$$a_c < 1. \tag{42}$$

Thus, similar to Acemoglu et al. (2006), if the R&D firms stick to the catch-up strategy, the country falls into a "non-convergence trap" in which the country's productivity level never catches up with the world technology frontier. The country converges to the world technology frontier only if its R&D firms shift to the innovation strategy at some point. However, the innovation strategy does not deliver

[16] The value of a_i is computed by replacing $a_t(i)$ and a_{t-1} in equation (36) as a_i.

[17] The value of λ_i is chosen to satisfy

$$1 = (1+g)\left[\lambda_i U(i)\right]^{-\alpha}. \tag{38}$$

[18] The value of a_c is computed by replacing $a_t(c)$ and a_{t-1} in equation (39) as a_c.

[19] This indeed turns out to be the case when we do the calibration in Section 5.

a higher growth rate for all levels of the distance from the the world technology frontier a_t. The next section analyses this issue.

3.2 Growth-maximising path

Inspection of equations (36) and (39) reveals that, as long as

$$[\lambda_S U(S)]^{\alpha} \gamma_S < 1, \quad S = c, i, \tag{43}$$

the growth rate of the economy is declining as the country approaches the world technology frontier. Furthermore, recall the assumption (12). Since $\eta_c > \eta_i$, if

$$[\lambda_c U(c)]^{\alpha} \gamma_c < [\lambda_i U(i)]^{\alpha} \gamma_i \tag{44}$$

holds, which we assume to be the case,[20] the growth rate is higher under the catch-up strategy than the innovation strategy when a_t is small enough (i.e. the technology level places the country relatively far from the frontier). Once a_t approaches unity (i.e. technology levels closer to the frontier), the catch-up strategy is dominated by the innovation strategy.

Given the government policy, the growth rate of the economy would be maximised for the entire transition path toward the world technology frontier if the R&D firms switched from the catch-up to innovation strategy after a_t exceeds a certain threshold (a given point on the way to the frontier). Such a value, a_g, solves

$$\frac{1}{1+g}[\lambda_i U(i)]^{\alpha}(\eta_i + \gamma_i a_g) = \frac{1}{1+g}[\lambda_c U(c)]^{\alpha}(\eta_c + \gamma_c a_g). \tag{45}$$

Therefore a_g is given by

$$a_g = \frac{\eta_c - \eta_i l}{\gamma_i l - \gamma_c}, \tag{46}$$

[20] Since $\gamma_i > \gamma_c$ and $\chi_i > \chi_c$, this condition holds as long as innovation is not significantly harder to achieve than catch up, i.e. as long as λ_c is not too much larger than λ_i.

where

$$l = \left(\frac{\lambda_i U(i)}{\lambda_c U(c)}\right)^\alpha = \left[\frac{\lambda_i(\chi_i - 1)(\chi_c + \sigma - 1)}{\lambda_c(\chi_c - 1)(\chi_i + \sigma - 1)}\right]^\alpha . \tag{47}$$

The above analysis implies that the R&D firms' profit from choosing innovation is higher than the profit from choosing catch up when the distance from the frontier is small enough. However it is not necessarily obvious whether the R&D firms switch their R&D strategy from catch up to innovation at a_g. Their decisions depend on the size of the fixed cost κ_s, factor prices, as well as government policy. In what follows we analyse the R&D firms' R&D strategy choice jointly with the choice of government policy, and characterise the equilibria of the model economy.

4 Equilibrium R&D Strategy Choice and Government Policy Choice

In this section we describe the strategy/policy choices of the R&D firms and the government, and then characterise the equilibria of the model economy. R&D firm choice depends on equilibrium aggregate variables and government policy. Government policy in turn depends on R&D firms' strategy choice. We continue to consider symmetric equilibria in which all R&D firms make identical decisions.

4.1 R&D firms

Here we analyse the choice problem facing the individual R&D firm which takes as given both aggregate variables and government policy. From equation (17), the profit function of R&D firm v choosing R&D strategy s at time t (given government policy p and the choice of other R&D firms S) is given by:

$$V^v_{s,t}(S,p) = \delta^v_s A^v_t(s) N_t(S,p) - W_{U,t}(S,p) U^v_t(s) - \kappa^v_s(p) \bar{A}_{t-1}, \tag{48}$$

where

$$\delta_s^v \equiv (\chi_s^v - 1)(\chi_s^v)^{-\frac{1}{\sigma}} \tag{49}$$

$$A_t^v(s) = [\lambda_s^v U_t^v(s)]^{\alpha} \left(\eta_s^v \bar{A}_{t-1} + \gamma_s^v A_{t-1}\right). \tag{50}$$

and

$$\kappa_s^v(p) = \begin{cases} \kappa_p & \text{if } s = i, \\ 0 & \text{if } s = c. \end{cases} \tag{51}$$

In equations (48) to (50), in order to distinguish clearly the variables specific to firm v from aggregate variables, we put superscript "v" to those which are specific to firm v. R&D firm v takes $N_t(S,p)$ and $W_{U,t}(S,p)$ as given.

R&D firm v maximises its profits (48) by choosing its R&D strategy $(s = i, c)$, as well as the amount of R&D labour to hire $(U_t^v(s))$. The evolution of $A_t^v(s)$ is given by equation (50). The optimal demand for R&D labour for each technology choice $(s = i, c)$ satisfies the first order condition

$$\alpha\delta_s^v(\lambda_s^v)^{\alpha}(U_t^v(s))^{\alpha-1}\left(\eta_s^v\overline{A}_{t-1} + \gamma_s^v A_{t-1}\right) = W_{U,t}(S,p) \tag{52}$$

We note that the firm takes $N_t(S,p)$ and $W_{U,t}(S,p)$ as given but those variables depend on the choices of other firms and the government in equilibrium. As we mentioned, we focus our analysis on symmetric equilibria in which all R&D firms make identical decisions. Let $V_{s,t}^v(N_t(S,p), W_{U,t}(S,p), \tau_p, \kappa_p)$ denote the maximised value of firm v making technology choice s with $N_t(S,p)$, $W_{U,t}(S,p)$, τ_p and κ_p as given. Firm v chooses the innovation strategy, $s = i$, if and only if

$$V_{i,t}^v(N_t(S,p), W_{U,t}(S,p), \tau_p, \kappa_p) > V_{c,t}^v(N_t(S,p), W_{U,t}(S,p), \tau_p, 0). \tag{53}$$

4.2 Government

As explained in Section 2, the government chooses τ_p and κ_p to maximise its objective function. Recall that we consider a choice of two policies: reform or status quo. Let $\Gamma_t(S, p)$ denote the payoff for the government when it chooses policy p and the R&D firms choose technology S:

$$\Gamma_t(S,p) = \varphi \sum_{i=0}^{\infty} \beta^i Y_{t+i}(S,p) + (1-\varphi) V_t(S,p) - \omega_p \bar{A}_{t-1} \tag{54}$$

where $Y_t(S, p)$ denotes the level of output when all firms choose the same strategy S (and government policy is p). From equation (26),

$$Y_t(S,p) = \frac{1}{1-\sigma} \chi_S^{\frac{\sigma-1}{\sigma}} N(S,p) A_t(S), \tag{55}$$

where $N(S, p)$ and $A_t(S)$ are given as equations (24) and (31), respectively. Taking as given the technology choice of the firms ($S = i, c$), the government chooses reform ($p = r$) if and only if

$$\Gamma_t(S,r) > \Gamma_t(S,q). \tag{56}$$

4.3 Definition of Symmetric Equilibrium

A symmetric equilibrium of the model economy is defined as follows. An equilibrium is a sequence of prices ($W_{N,t}$, $W_{U,t}$, P_t^v for all $v \in [0, 1]$), quantities (Y_t, N_t, X_t^v, U_t^v, A_t^v for all $v \in [0, 1]$), choice by R&D firm v (i.e., $s = i$ or c for all $v \in [0, 1]$), and choice by the government (i.e., $p = q$ or r) such that the household maximises its utility, the firms maximise their profits, the government maximises its payoff, and markets clear. A symmetric equilibrium is the one in which all firms make identical decisions (i.e., $P_t^v = P_t$, $X_t^v = X_t$, $U_t^v = U_t$, $A_t^v = A_t$ for all $v \in [0, 1]$, and all firms make the same strategy choice $s = i$ or c). In this equilibrium, the price of each intermediate good is given by $P_t^v = \chi_s$ for all $v \in [0, 1]$, and ($W_{N,t}$, $W_{U,t}$, Y_t, N_t,

U_t, A_t) are given by equations (24) – (31). The R&D technology choice satisfies equation (53), and the choice by the government satisfies (56).

Now we are ready to characterise the interaction between R&D firms' research strategy and the government policy. In what follows, we characterise the equilibria of the model by using a calibrated model. Details of the computation of symmetric equilibria are given in Appendix.

5 Model Calibration

We calibrate parameter values to replicate the empirical relationship between the growth rate of labour productivity and the distance from the world technology frontier, which is shown in Figure 1. For the R&D function parameters, we calibrate η_c, η_i, γ_c, γ_i, λ_c and λ_i to match the inverse relation between the distance from the frontier and the growth rate observed in major developed countries since the 1960s, which is illustrated in Figure 1. We also use $\eta_s + \gamma_s = 1$ $(s = i, c)$[21] and equation (45) in order to set these parameter values.

Turning to the other parameters determining firms' behaviour, the limit price parameter in the catch-up regime χ_c is calibrated at 1.1 to match the average of the profit-sales ratio across Japanese top-tier firms. We calibrate χ_i at 1.2 based on equivalent firms in the United States. We impose values on ϕ_N, and ϕ_U so that W_N/W_U in the model matches the wage ratio between college graduates and other workers in developed countries. We choose σ to reflect average labour share in major developed countries, while α is set so that U/N reflects the relative supply of college educated workers. In the model, the world technology frontier moves outward at a rate of two percent ($g = 0.02$) per year. This mimics the average annual growth of labour productivity in the United States since the 1960s.

We calibrate the policy-related parameters as follows. The installation cost of technology innovation κ_p is set to 0.004 under the status quo. This value is based on

[21] See footnote 10.

the ratio of cost of starting a business to the average profit of young small firms in Japan. We tentatively assume $\kappa_p = 0.003$ when the government chooses the reform policy. We set the labour wedge τ with reference to Shimer (2009) and Karabarbounis (2014), based on their measurements of the labour wedge in the United States. They find that the labour wedge in the United States has fallen between 0.3 and 0.5 since the 1970s. In the current paper, we assume that Japan faces greater labour market frictions than in the United States, and therefore calibrate the value of τ_q as 0.7 to capture this excess friction. We set τ_r to 0.4, on the understanding that reform would eliminate the excess and bring the wedge roughly down to its level in the United States. The list of the calibrated parameter values is shown in Table 1, and the implied values of equilibrium variables are shown in Table 2. Table 2 shows that output (y) and wages (w_N, w_U) are larger under reform than the status quo because the labour wedge is smaller. However, they are smaller under the innovation equilibrium because the price of intermediate goods is higher ($\chi_i > \chi_c$). On the other hand, the innovation equilibrium sustains a higher R&D labour input (U) through an increase in mark-up (δ) which raises the marginal product of R&D labour. Unfortunately we do not have an obvious target statistic for calibrating the reform cost ω. Currently we set $\omega = 5.75$ which implies that the political cost, envisaged as a series of costs incurred into the future, has a discounted present value equivalent to about 20% of current period output. Note that this cost does not only represent the monetary cost of political reform, but captures other costs such as time spent on political negotiations, time spent passing relevant laws, and opposition from interest groups.

Figure 1 plots the growth rates of labour productivity for selected OECD countries against the distance of each country from the world technology frontier. It shows that the growth rate decreases as a country moves towards the frontier. The growth-maximising path discussed in Section 3.2 is an envelope of the innovation line (thick-dashed) $a_t(i)$ implied by equation (36) and the catch-up line (thick-dashed)

$a_t(c)$ implied by equation (39). As is discussed in Section 3.2, the growth rate is higher under catch up when the distance from the frontier is large. Under our calibration, the model roughly captures the inverse relationship between the distance from the frontier and the growth rate. When the distance from the frontier is large (small a), the countries are closer to the catch-up line. On the other hand, as the distance from the frontier diminishes (a approaches unity), countries tend to fall around the innovation line. In recent years, many of these OECD counties can be regarded as within the innovation regime. However, some countries, including Japan, have started deviating from the innovation line. We will offer an explanation for this observation in Section 6.

6 Complementarity of technology choice and government policy: multiple equilibria

6.1 Multiple equilibria

In our model, economic reform by the government and R&D firm innovation are complements. On the one hand, equation (48) shows that the value of the firm depends positively on $N_t(S,p)$ and $W_{U,t}(S,p)$, which depend negatively on the government choice of τ_p. Thus the benefit to firms from increasing χ_s and A_t by switching to innovation from catch up is higher when τ_p is lower. Similarly, the value of R&D firms depends negatively on κ_p. The implication is that firms have a greater incentive to shift to innovation if the government chooses reform. On the other hand, equation (54) shows that the benefit to the government depends on the size of output and firms' profits. Meanwhile, equation (55) implies that the benefit from reform (i.e., decreasing τ_p thus increasing $N_t(S,p)$) is higher when $A_t(S)$ is higher.

Recall that, after the growth-maximisation point $a_t > a_g$, productivity level A_t is higher if firms choose innovation over catch up. After this point, therefore, the government has a higher incentive to choose reform if firms choose innovation. The implication is that the economy may exhibit multiple equilibria for distances from the frontier in a region close to a_g in which neither government nor the R&D firm has a strongly dominant strategy. In one equilibrium, the government chooses reform and firms choose innovation. In the other equilibrium, the government chooses the status quo and firms choose catch up.

Figure 2 shows that the economy has two equilibria in the region where its productivity is still an intermediate distance from the frontier. Intuitively speaking, R&D firm profits are higher following the catch-up strategy when the distance from the frontier is large (i.e., for lower values of a) because the rate of growth of productivity A_t is higher under the catch-up strategy than innovation. When a is sufficiently small, firms are better off choosing catch up regardless of the government's policy choice over reform. As the distance from the frontier diminishes (a draws closer to unity and productivity rises), the relative benefits of innovation increase. Since installing innovative technology is costly (higher value of κ), firms will choose to innovate only if the government implements reform. When the government decreases the labour market distortion τ, the size of the market increases and the benefit of installing innovative technology becomes large enough to compensate for the higher κ. [22] However, when the government elects not to reform, the market size remains small and the installation costs of the new technology outweigh its benefits.

Similarly, the incentive of the government to implement reform depends on how the reform increases the market size. Implementing reform incurs a political cost ω. Therefore the government implements the reform only if the benefit fully compensates for the cost. The objective function of the government comprises a weighted average of aggregate output and firm profits (equation (22)), and this depends positively on the technology level.[23] After the growth-maximising switching point

[22] Note that the government can also reduce κ to induce firms to switch to the innovation strategy. However, under our calibration, the main driver of the multiple equilibria is τ.

[23] The government's payoff is linear in technology level. See equations (55) and (A.1) in Appendix.

$(a_t > a_g)$, the benefit of government reform is higher if firms choose to innovate.

To sum up, when a is sufficiently small, there is a unique equilibrium: firms choose catch up and the government chooses the status quo. Similarly, when a is sufficiently large (i.e. a approaches unity), the equilibrium is unique: innovation and reform. When, however, a falls with a given intermediate range, there are multiple equilibria.

6.2 The non-convergence trap as a vicious cycle

Under our calibration, this region of multiple equilibria results in the emergence of a non-convergence trap, where a country may fall into a vicious cycle. Firms in the non-convergence equilibrium do not have enough incentive to innovate since the government fails to create an economic environment sufficiently favourable to their business activity. Meanwhile, the government does not have enough incentive to implement reform since there is insufficient overall economic activity to compensate for the costs of the reform. Moreover, even if a country in this region of multiple equilibria is fortunate enough find itself in the innovation equilibrium path, this fortuitous state of affairs is not robust to a shift in market sentiment: if either firms or government become pessimistic, the country may fall into the non-convergence equilibrium of catch up without reform.

Figure 2 indicates that since the 1980s Japan has been in the region of multiple equilibria and thus may well be caught in a vicious cycle of this type. Our hypothesis is the following. The catch-up phase for the Japanese economy ended during the 1970s, after which it shifted onto the growth-path traced out by the innovation regime. For example, until the 1980s, the Japanese car and semiconductor industries enjoyed a high degree of competitiveness in world markets that was rooted in their innovative technologies. However, the collapse of the asset price bubble followed by the banking crisis of 1997 had a negative impact on sentiment in Japan, with firms becoming pessimistic about the outlook for the Japanese economy. With the government preoccupied with clearing up post-bubble problems in the banking sector, Japanese firms may have believed there was little room for the government to spend scarce political capital implementing business-friendly reforms. Such a negative outlook on the likelihood of economic reform would have reduced firms' incentives to engage in costly innovation. Meanwhile, from the government's perspective, reforms such as those to the labour market could in practice create "losers." This would make it harder for the government to decide to implement economic reform when the economy is far from the frontier.

Thus firms' reluctance to innovate and the government's reluctance to implement painful reform can reinforce each other. A country which switches in this way from the innovation regime to the catch-up regime incurs the risk of falling into the "vicious cycle" non-convergence steady state. In this cycle, the growth rate of the economy will be consistently lower than that of the US, and the distance from the frontier will consequently widen. This appears to be consistent with observations of the Japanese economy since the 1990s.

7 Creating a virtuous cycle

In this section we conduct several experiments to investigate how a country can escape from the vicious cycle.

7.1 Removal of labour market distortions due to private employment practice/contract

In our model, the extent of distortion in the labour market is represented by the labour wedge: the discrepancy between the marginal product of labour and the marginal rate of substitution between consumption and leisure. As discussed in Section 2.1, the labour wedge captures labour market distortions resulting from both government policies and firms' employment practices such as lifetime employment and seniority-based wages. Under such systems, wage profiles do not necessarily match marginal product of labour profiles over employee life-cycles. When societal ageing raises the average age of workers, firms may end up paying higher wages (Naganuma and Nishioka (2014)), creating a higher labour market wedge. In addition, it is well-known that Japan lacks secondary markets for mid-career workers.

In this subsection, we assume that firms reduce the extent to which they apply norms of life-time employment and seniority-based wage setting, and then analyse the effects of this shift on both government incentives to implement reform and on R&D firms' incentive to innovate. In our model, the removal of this type of distortion is represented by a reduction in the labour wedge τ_p. Specifically, we decrease both τ_q and τ_r by the same magnitude.[24]

Figure 3 shows the results. The region of multiple equilibria shifts leftwards, covering a range of smaller values of a. For our calibration, this means that Japan is no longer caught in in the region of multiple equilibria (it can escape from the vicious cycle). It will move onto an innovation equilibrium path and its productivity will eventually converge to that of the US economy. This happens because the structural change affects the government's incentive to implement reform significantly. Intuitively speaking, a structural change in the private sector's employment practices (a reduction in τ_q and τ_r) has the potential to increase employment and thus the size of the economy. This has a positive impact on the government's incentive to implement reform, which in turn has a knock-on effect on the R&D firm incentives to innovate.

In reality, changing employment practices can be costly to private-sector firms which have to negotiate with labour unions. Here we do not model these costs. Nonetheless, this analysis implies that growth-enhancing initiatives in the private sector can reinforce the government's incentive to implement reform and thus R&D firm's incentive to innovate.

[24] For the purposes of fair comparison we decrease τ_q and τ_r so that both $\frac{1}{1+\tau_q}$ and $\frac{1}{1+\tau_r}$ increase by a magnitude of 10%.

7.2 Increasing labour supply

Second, we consider the equilibrium effects of changes in the labour supply. What we have in mind is an increase in female labour force participation. The female labour force participation rate in Japan has increased in recent years, but it is still below that of many OECD countries. Modelling details of female labour supply decisions is beyond the scope of our paper. However, we can nonetheless analyse the effects of an increase in labour supply on the incentives of the government to implement reform and of the R&D firms to innovate. Here the increase in labour supply is represented by a reduction in the parameter that controls the disutility of labour of the representative household, ϕ_N. Figure 4 shows the results. Similarly to the previous subsection, increasing labour supply increases the size of the economy. This effect in turn increases the incentive of the government to implement economic reform and so puts an end to the vicious cycle.

As a corollary of the above, ageing could enhance the vicious cycle because a reduction in the size of the labour force decreases the size of the economy. As discussed in Section 1, an ageing and shrinking working population is one of the most serious problems facing the Japanese economy today. Our model features a representative household, so it does not allow us to formally analyse the effects of demography. However, a decline in the labour supply due to societal ageing can be proxied by an increase in ϕ_N. Figure 5 shows the effects of an increase in ϕ_N on the economy. The region of multiple equilibria expands and there is thus an increased likelihood of Japan falling into the non-convergence trap. The implication is that Japan faces significant economic costs by failing to take measures to address its declining labour force.

8 Conclusion

By using a model of distance from the world technology frontier, we argue that private-sector innovation and government economic reform can reinforce each other. This is because, from a theoretical point of view, both innovation and economic reform involve fixed costs while the benefits accruing to them depend on the size of the economy. Government reform may increase the rewards from private sector innovation, while the latter may in turn increase the benefits of economic reform. The conclusion is that the private sector and the government must move in concert. Otherwise, the economy may fall into a self-fulfilling vicious cycle in which firms' innovation stagnates and the government fails to execute economic reform. Under our calibration, the risk of falling into a vicious cycle is large in a region at an intermediate distance from the world technology frontier, and Japan may indeed be in that situation. Our analysis implies that the slow productivity growth of the Japanese economy since the 1990s may have been compounded by lacklustre economic reform and insufficient innovation.

Where the costs of major reforms are large, there could be significant benefits from encouraging certain types of structural change: specifically, those that increase the size of the economy. The experiments in Section 7 provide examples of such structural changes. These are able to stimulate the economy, increasing the benefits from even politically challenging economic reforms enough to outweigh their costs, thus eliminating the vicious cycle and creating a virtuous one.

In this paper we do not model the details of the distortions in the labour and product markets. Representing those distortions, respectively, by the labour wedge (τ) and installation cost (κ) allows us to analyse the interaction between private sector R&D activities and government reform in a tractable framework. But this is, admittedly, a short cut. Modelling these distortions in a more explicit way would enable us to analyse the incentive problems of various interest groups. We leave this as a challenge for future research.

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Appendix

A Computation of symmetric equilibria

In the appendix, we first describe how an individual R&D firm and the government make their decisions. We then explain types of symmetric equilibria that emerge for each value of the distance from the world frontier a_{t-1}.

A.1 Individual R&D firm

Here we describe the behaviour of each R&D firm. Each firm v is small and it takes as given the aggregate variables and the behaviour of the other firms ($S = i, c$). It also takes the government policy as given ($p = r, q$).

Recall that $V^v_{s,t}(S, p)$ (given by equation (48)) denotes the profit function of the R&D firm v which chooses technology s at time t, taking as given the decisions of all the other firms S and the government policy p. After substituting the optimal demand for labour (52), $V^v_{s,t}(S, p)$ is given by

$$V^v_{s,t}(S, p) = (1 - \alpha)\delta^v_s A^v_t(s)N(S, p) - \kappa^v_s(p)\bar{A}_{t-1}, \tag{A.1}$$

where

$$\delta^v_s \equiv (\chi^v_s - 1)(\chi^v_s)^{-1/\sigma}. \tag{A.2}$$

Let $\Lambda^v_{s,t}(S, p) \equiv \frac{V^v_{s,t}(S,p)}{\bar{A}_{t-1}}$ denote the detrended profit. It is given by

$$\Lambda^v_{s,t}(S, p) = (1 + g)(1 - \alpha)\delta^v_s a^v_t(s)N(S, p) - \kappa^v_s(p), \tag{A.3}$$

where $a^v_t(s)$ evolves according to

$$a^v_t(s) = \frac{1}{1 + g}\left[\lambda^v_s U^v_t(s)\right]^\alpha \left[\eta^v_s + \gamma^v_s a_{t-1}\right]. \tag{A.4}$$

In a symmetric equilibrium with R&D strategy $S = i, c$, all the firms choose S if

$$\Lambda^v_{S,t}(S,p) \geq \Lambda^v_{s,t}(S,p), \quad s \neq S \text{ for all } v. \tag{A.5}$$

In other words, it is optimal for any firm v to choose S given that all the other firms choose S.

By using the first order condition for optimal labour (52) for each case of s and S, we obtain a relationship between $U^v_t(s)$ and $U_t(S)$ as

$$U^v_t(s) = \Phi_t(s,S)\, U_t(S), \tag{A.6}$$

where

$$\Phi_t(s,S) \equiv \left[\frac{\delta_s(\lambda_s)^\alpha(\eta_s + \gamma_s a_{t-1})}{\delta_S(\lambda_S)^\alpha(\eta_S + \gamma_S a_{t-1})}\right]^{\frac{1}{1-\alpha}}.$$

Since $a_t(S)$ is defined as

$$a_t(S) \equiv \frac{1}{1+g}[\lambda_S U(S)]^\alpha[\eta_S + \gamma_S a_{t-1}], \tag{A.7}$$

where $U(S)$ is given by equation (25), equation (A.6) implies

$$a^v_t(s) = \frac{\delta_S}{\delta_s}\Phi_t(s,S)\, a_t(S). \tag{A.8}$$

By using equations (A.3) and (A.8), condition (A.5) can be written as

$$\begin{aligned}(1+g)(1-\alpha)N(S,p)\delta_S a_t(S) - \kappa_S &\geq (1+g)(1-\alpha)N(S,p)\delta^v_s a^v_t(s) - \kappa^v_s \\ &= (1+g)(1-\alpha)N(S,p)\delta_S a_t(S)\Phi_t(s,S) - \kappa^v_s\end{aligned} \tag{A.9}$$

In order to interpret condition (A.9), suppose for example $S = i$ (innnovation). Equation (A.9) implies that, given policy p, symmetric innovation equilibrium can exist if

$$(1+g)(1-\alpha)N(i,p)\delta_i a_t(i) - \kappa_i \geq (1+g)(1-\alpha)N(i,p)\delta_i a_t(i)\Phi_t(c,i)\,. \qquad \text{(A.10)}$$

(Note that $\kappa_c = 0$.) Term $\Phi_t(c,i)$ represents the extra benefit (or cost) of choosing catch-up strategy in terms of productivity growth and changes in markup (δ_c versus δ_i). The assumptions $\eta_c > \eta_i$ and $\gamma_c < \gamma_i$ imply that $\Phi_t(c,i)$ is decreasing in a_{t-1}. Under our calibration, $\Phi_t(c,i) > 1$ when a_{t-1} is small and then eventually $\Phi_t(c,i) < 1$ as a_{t-1} becomes larger. This implies that symmetric innovation equilibrium exists when a_{t-1} is large enough. More precisely, let $\tilde{a}^{i,r}$ be the threshold value such that (A.10) holds with equality when the government policy is $p = r$. Then the symmetric innovation equilibrium exists if $a_{t-1} \geq \tilde{a}^{i,r}$. Analogously, for the catch-up strategy we can define $\tilde{a}^{c,r}$. Regarding the case in which the government chooses status quo ($p = q$), we can define $\tilde{a}^{c,q}$ and $\tilde{a}^{i,q}$ in a similar way. To summarise, we compute four thresholds for the R&D firm v, namely, $\tilde{a}^{i,q}$, $\tilde{a}^{c,q}$, $\tilde{a}^{i,r}$, and $\tilde{a}^{c,r}$. We employ a grid-search approach in computation because we cannot obtain analytical solutions for the thresholds.

A.2 Government

Given the technology choice of the firms ($S = i, c$), the government decides the current policy: $p = q, r$ (reform or status quo). Recall that the payoff of the government who chooses policy p, taking technology choice S as given, is

$$\Gamma_t(S,p) = \varphi \sum_{j=0}^{\infty} \beta^j \frac{Y_{t+j}(S,p)}{\bar{A}_{t-1}} + (1-\varphi)\Lambda_t(S,p) - \omega_p, \qquad \text{(A.11)}$$

where $Y_t(S,p)$ denotes the level of final goods output at time t under technology choice S and policy p. Upperscript "v" is suppressed since we analyse symmetric equilibrium in which all the R&D firms choose the same strategy. Rearranging the first term of the equation (A.11), we obtain

$$\sum_{j=0}^{\infty} \beta^j \frac{Y_{t+j}(S,p)}{\bar{A}_{t-1}} = y(S,p)(\lambda_S U(S))^{\alpha} \sum_{j=0}^{\infty} [\beta(1+g)]^j \left(\eta_S + \gamma_S a_{t+j-1}(S)\right). \tag{A.12}$$

where

$$y(S,p) = \frac{1}{1-\sigma}\chi_s^{\frac{\sigma-1}{\sigma}} N(S,p) = \frac{1}{1+\tau_p}\frac{1}{1-\sigma}\chi_s^{\frac{\sigma-1}{\sigma}} \frac{\sigma\chi_s}{\phi_N(\chi_s+\sigma-1)},$$

and $a_{t+j}(S)$ evolves according to (A.7). Thus, we can obtain the value of the output-related benefit for a certain policy choice p by computing the equation (A.12).

We then consider the term on the firms' profit in the equation (A.11). From equation (A.3), we have

$$\Lambda_t(S,p) = (1+g)(1-\alpha)\delta_S a_t(S) N(S,p) - \kappa_S(p), \tag{A.13}$$

where $a_t(S)$ is given by (A.7). Again, upper script "v" is suppressed. By using (A.13), we can obtain the payoff for the policy choice p given a_{t-1} and the strategy choice S.

The government chooses policy p if and only if

$$\Gamma_t(S,p) \geq \Gamma_t(S,p'), \quad p = r, q, \quad p' \neq p. \tag{A.14}$$

Inspection of equations (A.12) and (A.3) reveals that $\Gamma(S,p)$ is monotonically increasing in a_{t-1}. In addition to this, since $\tau_r < \tau_q$,

$$\frac{\partial \Gamma(S,r)}{\partial a_{t-1}} > \frac{\partial \Gamma(S,q)}{\partial a_{t-1}}. \tag{A.15}$$

Notice also $\omega_r > 0$ and $\omega_q = 0$. Therefore, given S, there exists a unique threshold value of $\hat{a}^S$ such that

$$\Gamma_t(S,r) = \Gamma_t(S,q) \tag{A.16}$$

and $\Gamma_t(S,r) > \Gamma_t(S,q)$ for $a_{t-1} > \hat{a}^S$, and $\Gamma_t(S,r) < \Gamma_t(S,q)$ for $a_{t-1} < \hat{a}^S$.

Since this study assumes two technology strategies ($S = i, c$), we compute two thresholds for the government, namely, $\hat{a}^i$ and $\hat{a}^c$. Again, we employ a grid-search approach in computing the thresholds.

A.3 Multiple equilibria

Based on the results of Sections A.1 and A.2, now we examine what types of equilibria emerge for each value of the distance from the frontier a_{t-1}. In the following, we analyse the interactions between the decision-making of the firms and the government.[25]

First, we consider the government's decision, taking the R&D firms' choice as given. Figure A1 maps the computed policy thresholds under our calibration on the horizontal axis which is a country's distance from the frontier at time $t-1$. In the Figure, $\hat{a}^i$ represents the value of a_{t-1} that satisfies equation (A.16) when the firms choose innovation ($S = i$). When $a_{t-1} < \hat{a}^i$, the government chooses status quo if the firms choose innovation. Similarly $\hat{a}^c$ represents the value of a_{t-1} that satisfies equation (A.16) when the firms choose catch up ($S = c$). As the figures depicts, the distance from the frontier is classified into the following three regions. If the economy stays between $0 < a_{t-1} < \hat{a}^i (< \hat{a}^c)$, status quo is chosen whichever the firms choose. If $\hat{a}^i \leq a_{t-1} < \hat{a}^c$, reform is implemented if the R&D firms take the innovation strategy, whereas status quo is chosen if the firms take the catch-up strategy. If $a_{t-1} \geq a^c$, reform is implemented regardless of the firms' choice. This result implies the possibility of multiple equilibria in the region of $\hat{a}^i \leq a_{t-1} < \hat{a}^c$.

Next, we combine the technology thresholds with those of the policy choice. Figure A2 projects the two thresholds of the technology choice given the status quo policy ($\tilde{a}^{i,q}$ and $\tilde{a}^{c,q}$) on the Figure A1. Since we are now considering the case in which the government chooses status quo, we focus on the region of $0 < a_{t-1} < \hat{a}^c$.[26] When

[25] We assume $\varphi = 1$ as in the main text.

[26] If $a_{t-1} \geq \hat{a}^c$, the government should choose reform, contradicting the assumption of the status

$0 < a_{t-1} < \tilde{a}^{c,q}$, all of the firms choose the catch-up strategy. As for the policy, the government takes status quo if the firms take the catch-up strategy, since $a_{t-1} < \hat{a}^c$ in this case. Consequently, $(p, s) = (q, c)$ is an equilibrium in the region. By contrast, if the economy stays $a_{t-1} > \tilde{a}^{c,q}$, the firms have incentive to choose innovation in symmetric equilibrium. Since $\tilde{a}^{c,q} > \hat{a}^i$, in this region the government does not have incentive to choose status quo if the firms choose innovation. Therefore, in region $\tilde{a}^{c,q} < a_{t-1} < \hat{a}^c$, there is no symmetric equilibrium in which the government chooses status quo.

Figure A3 considers the case in which the government chooses reform. Here we draw the two thresholds of the technology choice ($\tilde{a}^{i,r}$ and $\tilde{a}^{c,r}$) on the Figure A1. We do not consider region in which $a_{t-1} < \hat{a}^i$ because in this region the government will not choose reform regardless of the choice of the firms. Therefore we focus on the region of $a_{t-1} \geq \hat{a}^i$. Notice that, in this region, all of the firms choose the innovation strategy. As for the policy, $a_{t-1} \geq \hat{a}^i$ implies that the government implements reform. Consequently, $(p, s) = (r, i)$ is an equilibrium in the region.

To summarise, Figure A4 illustrates the types of equilibria against the country's distance from the frontier. If the economy stays $0 < a_{t-1} < \hat{a}^i$, there is unique symmetric equilibrium which is a combination of the status quo policy and catch-up strategy ($(p, s) = (q, c)$). In the region of $\hat{a}^c \leq a_{t-1} < \tilde{a}^{c,q}$, there are two equilibria, namely, i) the status quo policy and catch-up strategy ($(p, s) = (q, c)$), and ii) the reform policy and innovation strategy ($(p, s) = (r, i)$). If $a_{t-1} \geq \tilde{a}^{c,q}$, there is unique equilibrium which is a set of the reform policy and innovation strategy ($(p, s) = (r, i)$).

quo policy.

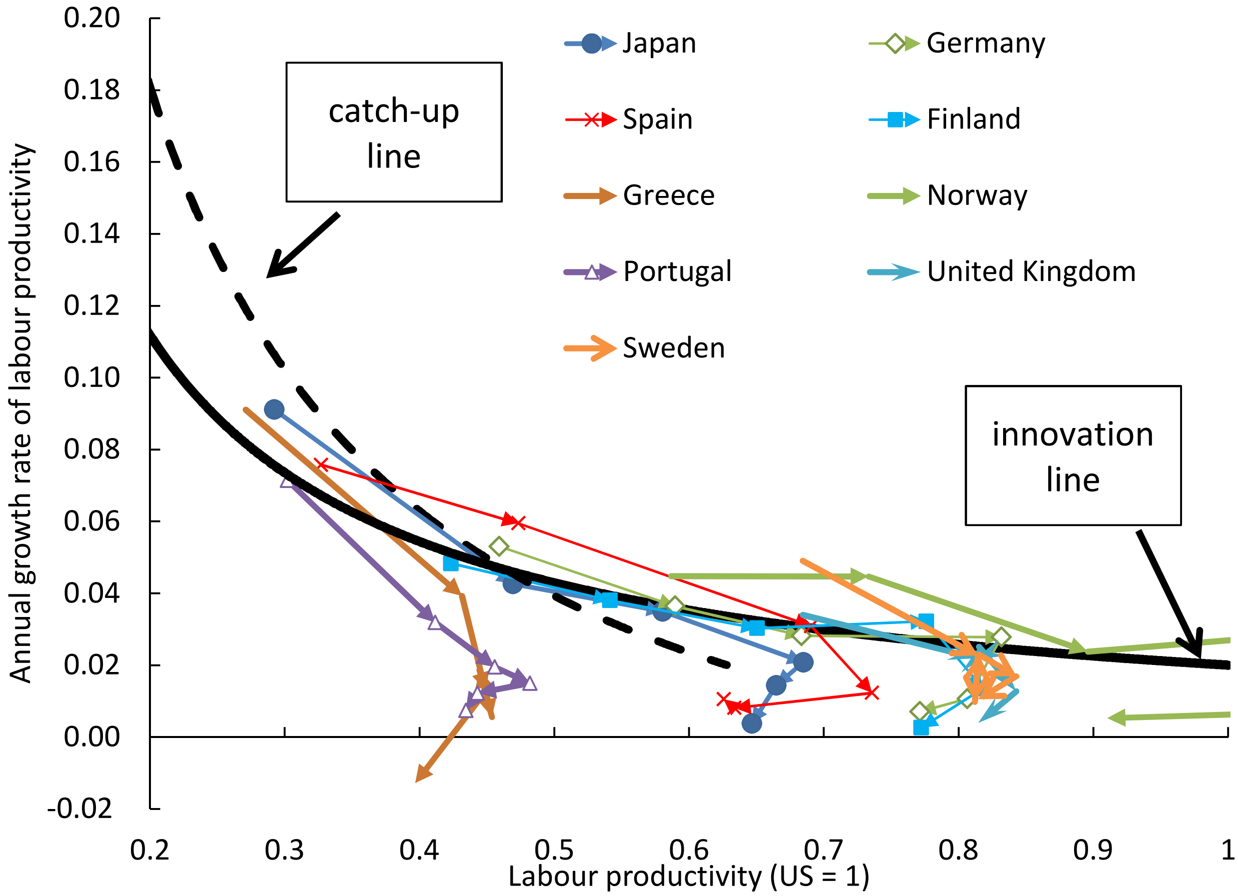
Table 1: List of Calibrated Parameter Values

Parameter		Strategy Catch up	Innovation
η	Spillover from frontier country	0.0476	0.0225
γ	Spillover from home country	0.9524	0.9775
λ	Efficiency of labour input	22.28	13.45
χ	Price of intermediate goods	1.10	1.20
κ_q	Fixed cost (R&D firms), status quo	0.000	0.004
κ_r	Fixed cost (R&D firms), reform	0.000	0.003
τ_q	Labour wedge (fin. goods sector), status quo	0.7	
τ_r	Labour wedge (fin. goods sector), reform	0.4	
σ	Parameter in prod. function (fin. goods)	0.5	
α	Parameter in prod. function (R&D)	0.8	
ϕ_N	Disutility of labour (production labour)	1.2	
ϕ_U	Disutility of labour (R&D labour)	1.0	
g	Growth rate of frontier country	0.02	
ω	Cost of reform policies	5.75	
φ	Weight on final goods output in goverment's objective function	1.0	
β	Household's discount factor	0.96	

Table 2: List of Computed Equilibrium Values

Parameter		Status quo Catch up	Status quo Innovation	Reform Catch up	Reform Innovation
y	Output of final goods	0.817	0.700	0.992	0.850
x	Output of intermediate goods	0.371	0.292	0.451	0.354
c	Consumption	0.446	0.408	0.541	0.496
N	Labour input (Final goods firms)	0.449	0.420	0.546	0.510
U	Labour input (R&D firms)	0.044	0.076	0.044	0.076
w_N	Wage (Final goods firms)	0.535	0.490	0.649	0.595
w_U	Wage (R&D firms)	0.668	0.613	0.812	0.744

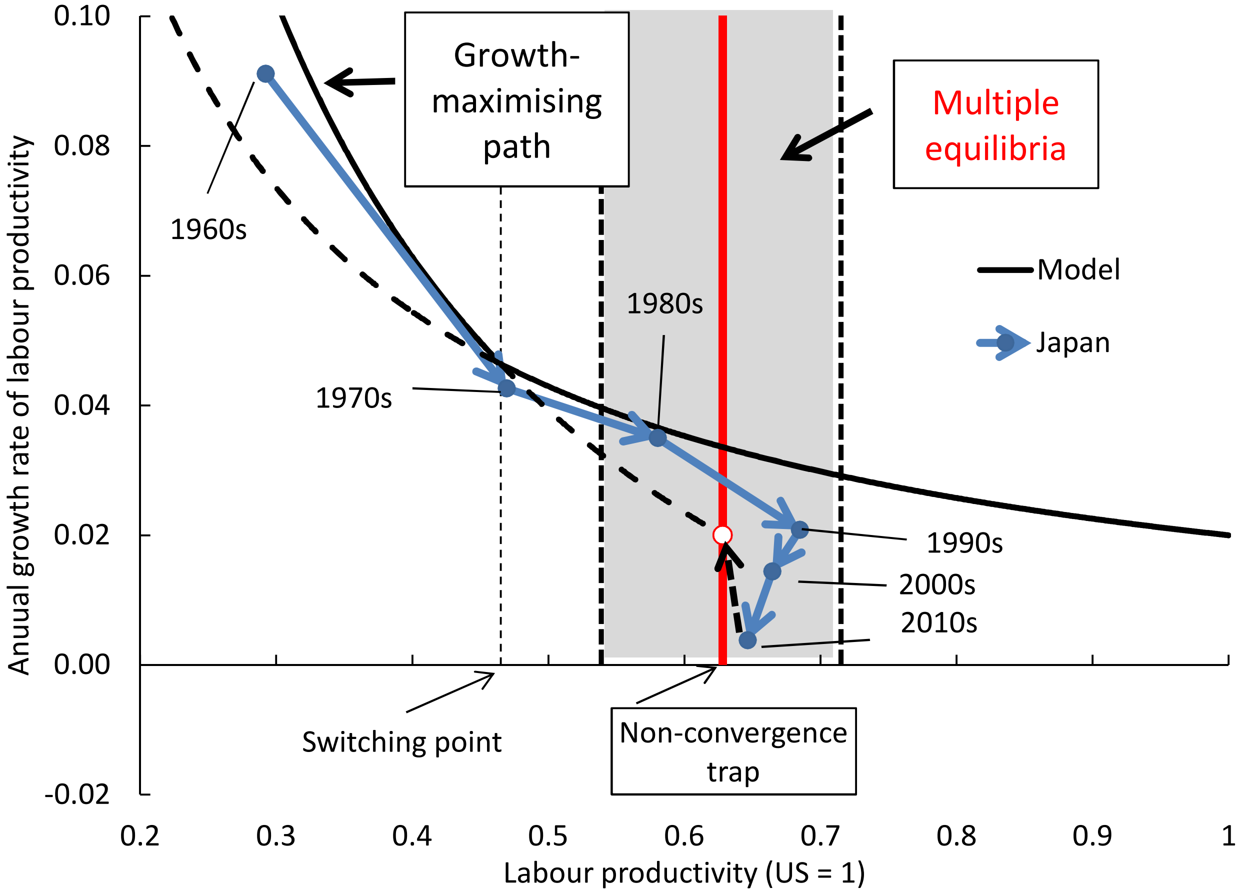
Figure 1. The growth rate of labour productivity and the distance from the world technology frontier



Note. The figure plots the movement over time of the growth rate of labour productivity against the distance from the world technology frontier for major developed countries between the 1960s and 2010s. The values for the 2010s are averages over the years 2010 to 2015. The innovation line (thick) and the catch-up line (thick-dashed) are given, respectively, by equations (36) and (39). The growth-maximising path is an envelope of these two lines. The distance from the frontier of Norway exceeds unity over the 1990s and 2000s, since the country records higher producitivity compared to the United States during the period.

Source. The Conference Board, "The Conference Board Total Economy Database™, May 2016"

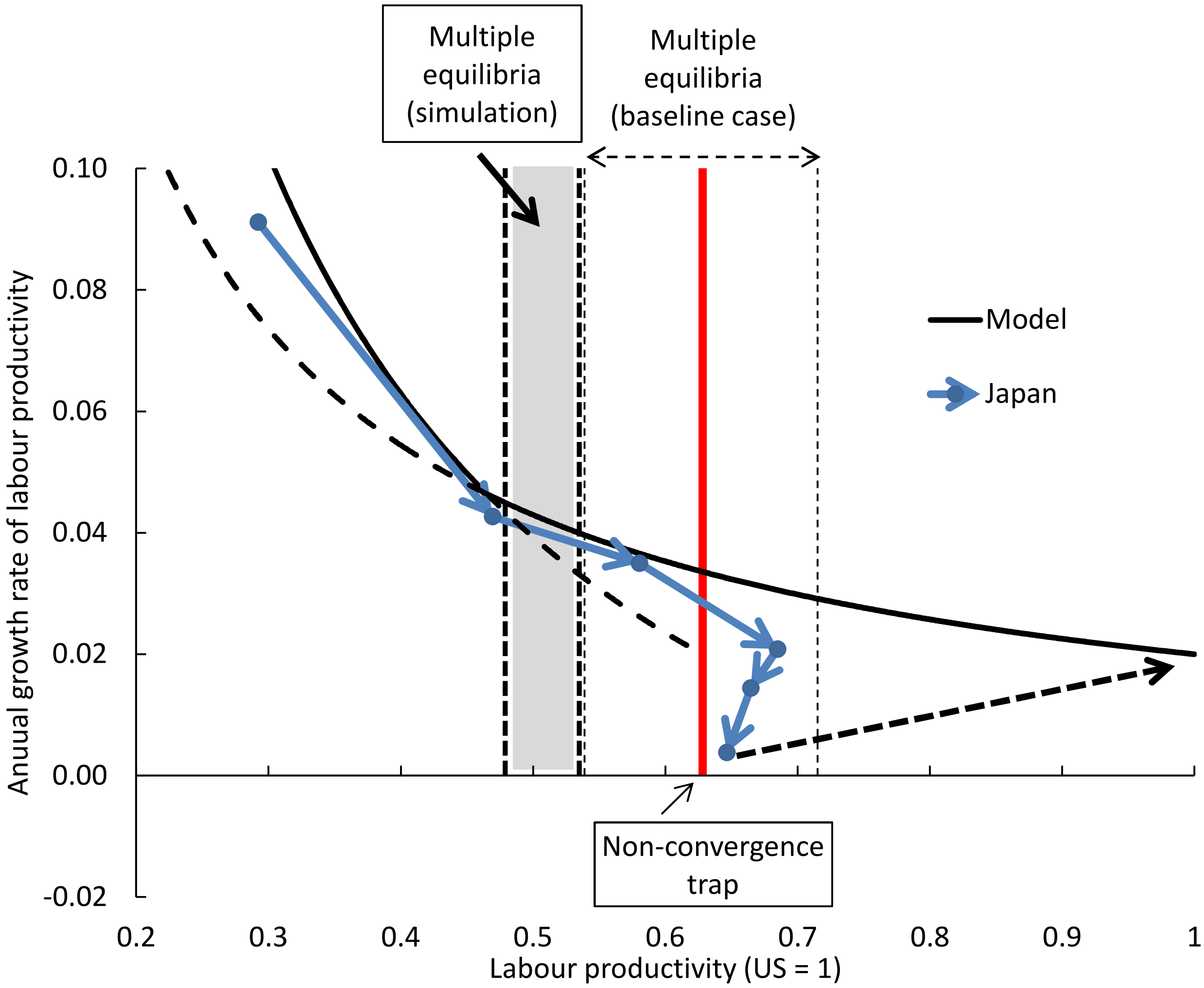
Figure 2. Multiple equilibria and non-convergence trap



Note. The thick arrows trace Japan's labour productivity growth against its distance from the world technology frontier since the 1960s. The values for the 2010s are averages over the years 2010 to 2015. The thick-dashed arrow is the future path of the Japan's productivity if the country would approach the non-convergence trap. The thick line is the growth-maximising path computed from equations (36) and (39), which are shown by the steep and flat thick-dashed lines; these plot the respective paths for firms adopting the innovation and the catch-up strategies. The switching point is a_g as computed from equation (46). The value of the non-convergence trap is given by equation (41). We compute the region of multiple equilibria in the figure using the equations given in Section 4. The resulting region is illustrated in the figure by the shaded area labelled "Multiple equilibria".

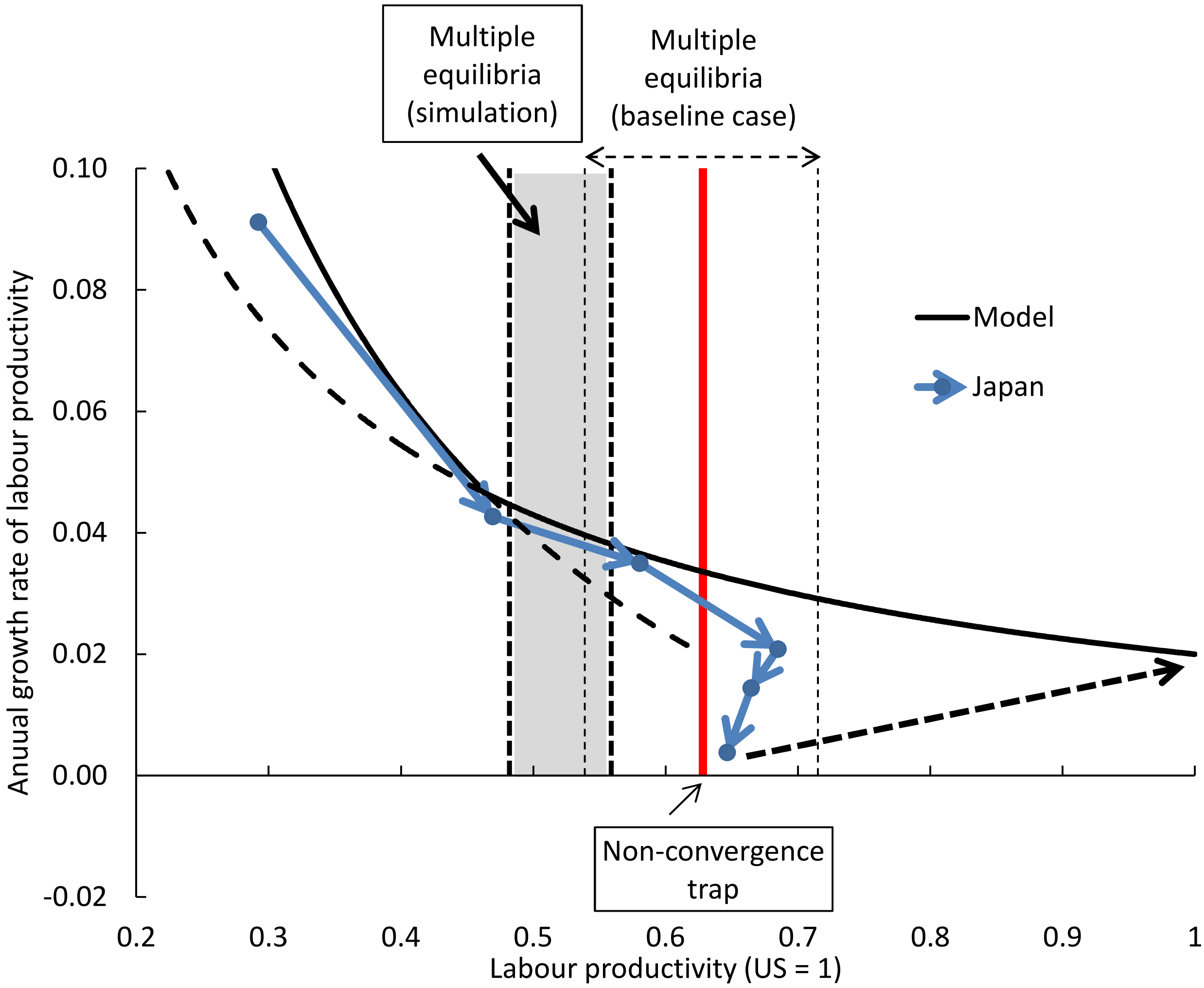
Source. The Conference Board, "The Conference Board Total Economy Database™, May 2016"

Figure 3. A decrease in the labour wedge initiated by the private sector



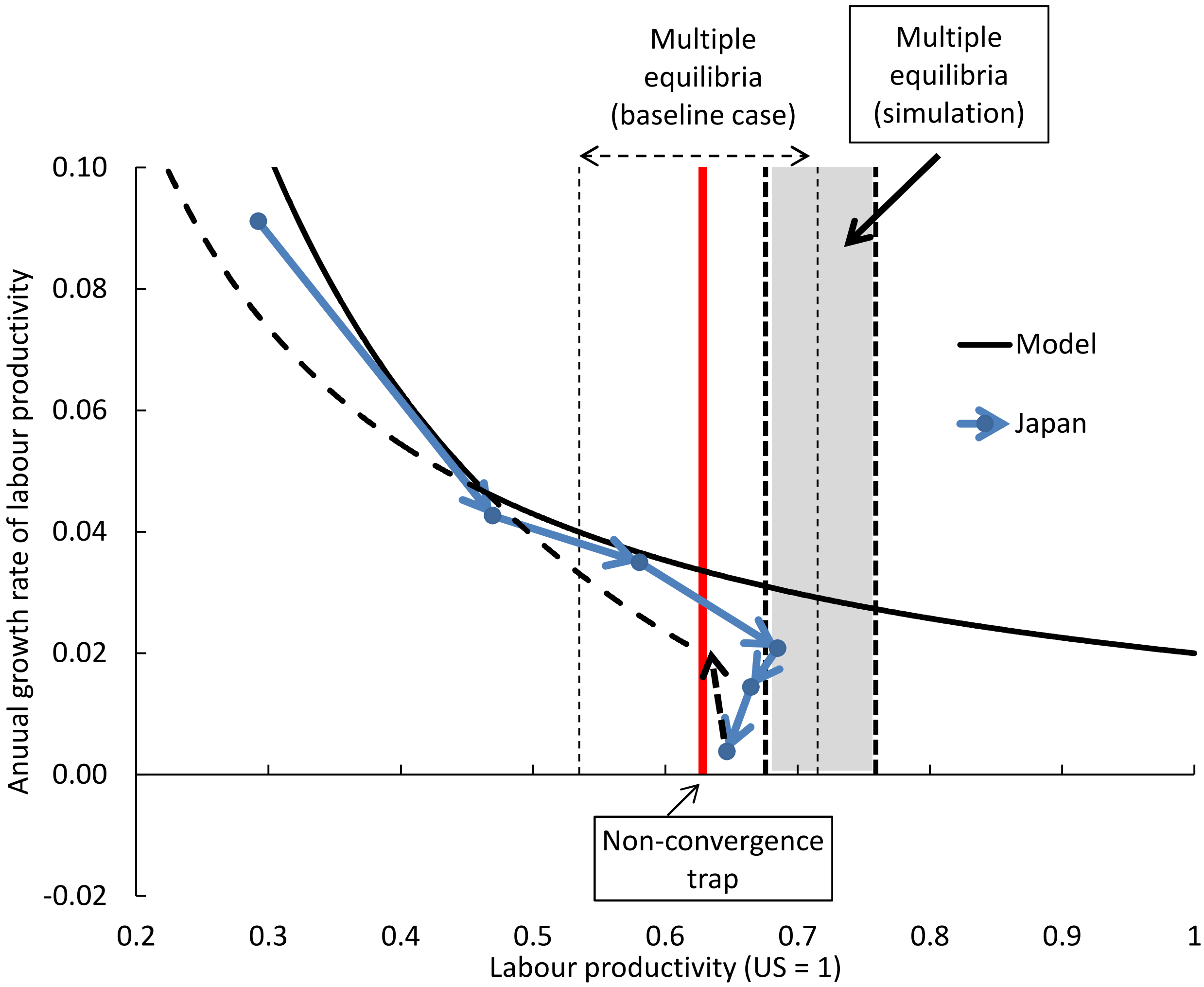
Note. We compute the region of multiple equilibria in the figure using the equations given in Section 4. For the simulation, we reduce the values of the labour wedge parameters for both "reform" and "status quo" cases so that both $(1/(1+\tau_q))$ and $(1/(1+\tau_r))$ increase by a magnitude of 10 percent. The resulting region of multiple equilibria is illustrated in the figure by the shaded area labelled "Multiple equilibria (simulation)". The multiple equilibria region computed in the baseline case, "Multiple equilibria (baseline case)" is the same as in Figure 2. The thick-dashed arrow is the future path of the Japan's productivity if it would converge to the productivity of the United States.

Figure 4. A decrease in the value of the labour disutility parameter



Note. We compute the region of multiple equilibria in the figure using the equations given in Section 4. For the simulation, we reduce the value of the labour disutility parameter from 1.2 to 1.1. The resulting region of multiple equilibria is illustrated in the figure by the shaded area labelled "Multiple equilibria (simulation)". The multiple equilibria region computed in the base case, "Multiple equilibria (base case)" is the same as in Figure 2. The thick-dashed arrow is the future path of the Japan's productivity if it would converge to the productivity of the United States.

Figure 5. An increase in the value of the labour disutility parameter



Note. We compute the region of multiple equilibria in the figure using the equations given in Section 4. For the simulation, we raise the value of the labour disutility parameter from 1.2 to 1.3. The resulting region of multiple equilibria is illustrated in the figure by the shaded area labelled "Multiple equilibria (simulation)". The multiple equilibria region computed in the base case, "Multiple equilibria (base case)" is the same as in the Figure 2. The thick-dashed arrow is the future path of the Japan's productivity if the country would approach the non-convergence trap.

Figure A1. The government' decisions and the distance from the frontier

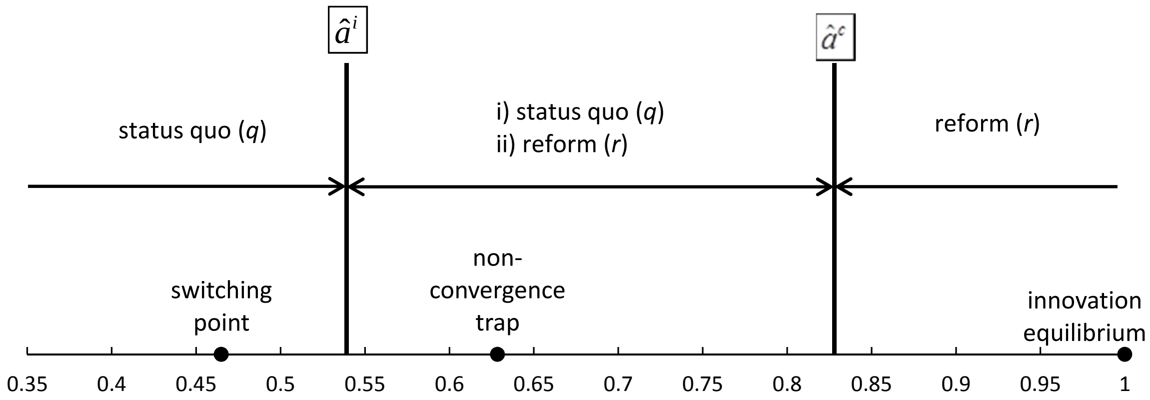


Figure A2. An individual firm's choice under the assumption of the status quo policy

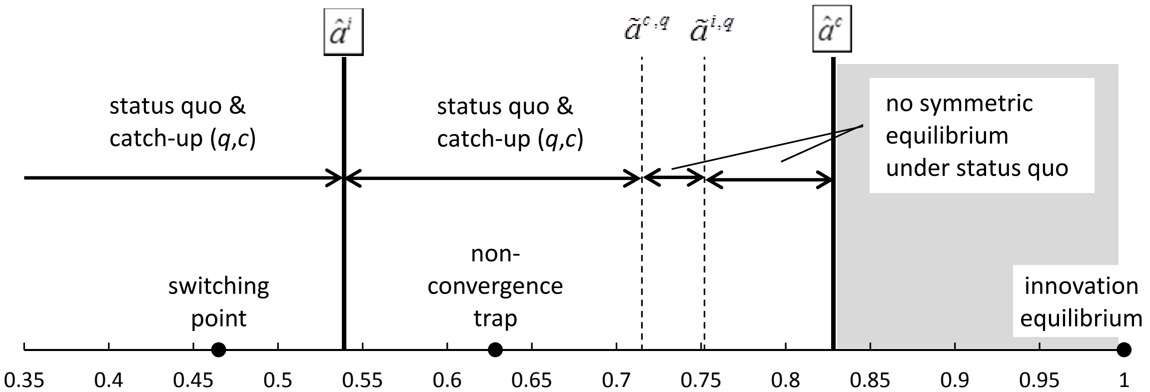


Figure A3. An individual firm's choice under the assumption of the reform policy

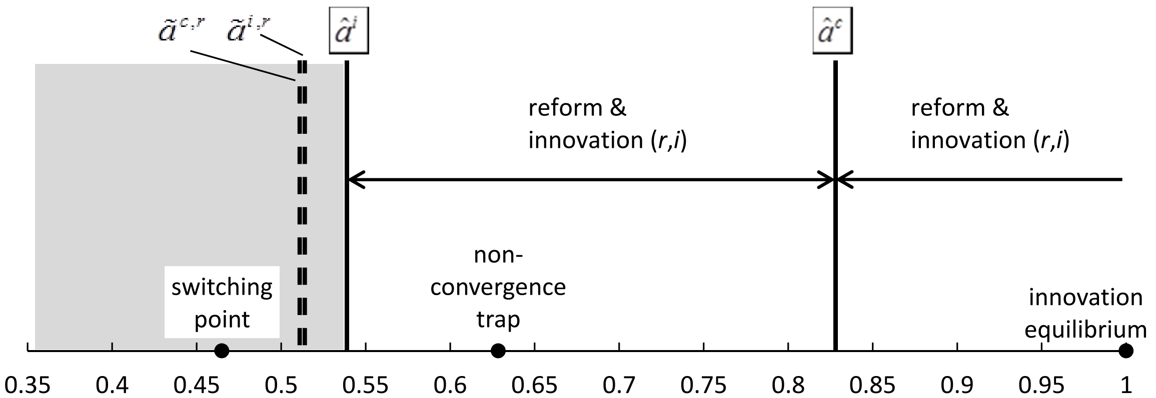


Figure A4. Resulting types of equilibria and the distance from the frontier