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Strategic policies and growth: an applied model of R&D-driven endogenous growth

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Abstract

We introduce and explore a general equilibrium model with R&D-driven endogenous growth, whose antecedents are the models of Romer (1990) [Romer, P.M., 1990. Endogenous technological change. Journal of Political Economy, 98, S71-102] and Grossman and Helpman (1991) [Grossman, G.M., Helpman E., 1991. Innovation and Growth in the Global Economy, The MIT Press, Cambridge]. Utilizing evidence from recent econometric studies on sources of growth, the model also accounts explicitly for cross-border technological spillovers. The model is specified and calibrated to data from Japan, and is solved to obtain both the transitional and the steady-state equilibria. We explore the effects of selective trade and R&D promotion policies on long-run growth and social welfare. The model results suggest that while a *strategic* trade policy has little effect on re-allocating resources into domestic R&D activities, it can significantly affect the cross-border spillovers of technological knowledge, which, in turn, stimulates growth. We find that trade liberalization may cause the growth rate to fall and lead to a loss of social welfare in the long-run, although it improves welfare in the short-run. R&D promotion policies stimulate growth by inducing

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private agents to allocate more resources to domestic R&D, as well as to take greater advantage of global R&D spillovers. Here, we find significantly high growth effects together with sizable gains in social welfare at low incidence to tax payers.

JEL classification: C68; F12; O33; O38; O41

Keywords: Applied general equilibrium; Endogenous growth; Strategic trade policy

1. Introduction and literature summary

The past decade witnessed a notable growth in empirical and analytical studies on the origins and causes of the wealth of nations. A variety of empirical evidence indicates that national growth rates are correlated with many economic, social and political variables, including many that are affected by government policies, while a number of analytical models tend to focus more narrowly on specific sources of growth. Together, these efforts explain many of what Kaldor (1961) and others refer to as the ''stylized facts'' of economic growth. [3] One strand of analytical models focuses on capital accumulation, broadly defined to include human capital, as the driving force behind economic growth (Jones and Manuelli, 1990; Rebelo, 1991; King and Rebelo, 1993). A second approach casts external economies in a leading role in the growth process. Each firm's investment in either physical (Arrow, 1962), or human capital (Lucas, 1988) inadvertently contributes to the productivity of capital held by others. The third approach, pioneered by Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992), focuses on the evolution and adoption of new ideas as an engine of growth. Profit-motivated industrial innovations in R&D lead to the accumulation of technological knowledge which is only partially excludable and non-rival, and hence, becomes a source of growth. This theory also draws attention to foreign trade as a transmission in linking a country's productivity gains with advances of technological knowledge in its trade partners.

A crucial feature of the R&D-driven growth theories is their explicit identification of the mechanisms by which government policies have permanent effects on the rate of long-run growth. In one specification of the model, the main source of

[3] Part of this literature is surveyed by Sala-i-Martin (1990), Helpman (1992), and Lucas (1993). See also the symposium in the special issue of the *Journal of Economic Perspectives* (1994, Vol. 8) with contributions of Grossman and Helpman (1994), Romer (1994), and Solow (1994) for a review. The recent books by Barro and Sala-i-Martin (1995) and Aghion and Howitt (1998) provide further sources of excellent reference. Finally, the *1998 / 1999 World Development Report* of the World Bank (1999) synthesizes the development policy implications of knowledge-driven growth.

growth originates only from own R&D. In this case, government can affect long-run growth by providing market incentives for commercial investment in research leading to new patents and blueprints. In another specification, a country can be thought of as having full access to the entire stock of global R&D, in which case policies that encourage openness in trade have strong effects on growth as international trade provides a mechanism through which technological knowledge developed elsewhere can be acquired domestically (Coe and Helpman, 1995).

These two specifications provide the insight and guidance of this study. It has to be noted, however, that as channels for obtaining growth, they are in actuality interdependent. While the process of cumulative own R&D depends on the growth in technological knowledge developed abroad, a country is only likely to have partial access to global R&D stock, depending on its technical sophistication and capacity in transmitting global R&D knowledge into the domestic economy. Clearly, countries can take advantage of the stock of knowledge developed elsewhere ''...only if they develop the technological competence to search for appropriate technologies and select, absorb, and adapt imported technology'' (World Bank, 1999, p. 8). Hence, policies which stimulate *own* R&D activities are important as well as the policies which take advantage of *global* R&D. Moreover, policies to stimulate own R&D and policies to stimulate knowledge spillovers from global R&D may be complementary in the sense that one makes the other more effective.

In this study, we primarily focus on the channels through which government policy can stimulate domestic R&D activity, and create a more conducive environment for international spillovers. For this purpose, we utilize a dynamic general equilibrium model which accommodates alternative policy instruments in a market setting, based on real country data. In so doing, we take account of the rapidly expanding stock of recent econometric evidence on the nature and extent of the positive linkages between a country's two sources of productivity growth, own R&D and the R&D of its trading partners.

Using a sample of 21 OECD countries plus Israel, Coe and Helpman (1995) (hereafter C&H) find that the rate of return on own R&D is not only high in the performing countries, but that significant benefits also accrue to their trade partners. They further argue that the cross-border spillover effects are stronger the more open an economy is in its trade with countries having high levels of R&D capital stock. For the construction of R&D capital stocks, they use cumulative R&D expenditure as a proxy, and foreign R&D stock is weighted by the trade share of the partner countries. Their approach is actually an innovation of the input–output based transmission model developed earlier by Terleckyj (1974), and later extended by Wollf and Nadiri (1993).

The C&H approach has been applied and extended by others. Using panel data of 10 OECD countries, Park (1995) found that at the national level, private sector research is the more significant determinant of productivity growth in comparison with the public sector. Public research activities, however, do have indirect effects on private R&D through generating cross-border spillovers into research. Furthermore, as a determinant of private sector productivity, foreign R&D spillovers have higher output elasticities, but the domestic private R&D is found to have a higher rate of return. In Park's view, because the bulk of the world's R&D activities occur in only a few countries, the variables capturing spillovers tend to dominate their domestic counterparts. Lichtenberg and de la Potterie (1996) extend the C&H investigation to include spillovers from foreign direct investment flows (as a proxy for the multinational corporations' technology transfers). Wang and Xu (1997) modified these specifications and, instead of using total imports as carriers of foreign technological knowledge, they focus exclusively on capital goods imports. Their conceptual argument was that capital goods imports would serve as a better proxy for knowledge carriers than total imports.

Utilizing the same approach, Coe et al. (1997) in return investigated the extent of the international spillovers of R&D from the industrial North to the less developed South. Based on data for 77 developing countries, they found evidence that R&D spillovers from the North to the South are substantial and ''that a developing country's total factor productivity is larger the larger is its foreign R&D capital stock, the more open it is to machinery and equipment (capital goods) imports from the industrial countries, and the more educated is its labor force'' (p. 135).

Similarly, Lee (1995) presented an endogenous growth model of an open economy in which the growth rate of income can be influenced by the ratio of imported to domestically produced capital goods in the composition of investment. He finds a significant and positive effect on per capita income growth rates as this ratio rises.

Following another route, Scherer (1984), Jaffe (1986), Branstetter (1996), and Keller (1997) claimed that studies employing country-level data miss much of the characteristics of the nature of technological knowledge flows, and focused instead on industry-level data between firms. Needless to assert, one may also claim that technology flows are not unidirectional; i.e., they are also transferred from the buyers to the sellers, or from the downstream to the upstream industries. This point is pursued in the work of Mansfield (1984).

Much of this literature is surveyed in the work of Taylor (1996) [4] wherein he also extends a model where government's incentives to restrict trade may endogenously change over time as growth alters the domestic production structure. Taylor

[4] The reader may also wish to take account of the remaining stock of the empirics of growth literature surmised here for space limitations. Barro (1991), Levine and Renelt (1992), Mankiw et al. (1992), Kortum (1993), Jones (1995a), Chari et al. (1996) and Eaton and Kortum (1996) are critical sources. See also the Bibliography presented in the World Bank (1999) and the papers by Hall and Jones (1997), Sachs and Warner (1997), and Sala-i-Martin (1997), in the Recent Empirical Growth Research session of Conference Proceedings (May 1997) issue of the *American Economic Review*.

also draws attention to the fact that much of the empirics of the trade policy implications of the new growth theory hinge upon the specification of the knowledge transmission function, whether it diffuses slowly over time or instantaneously.

All of this is not without its critics. Keller (1996), for instance, pointed out the fact that even if a relationship exists between the diffusion of technological knowledge and domestic factor productivity, it is difficult to give it a casual interpretation; that we may actually be observing a common time trend rather than spillovers. Yet, a ''deeper'' critique is that of Jones (1995a) who challenges the main premise of both the R&D and the AK-style models of endogenous growth that permanent changes in government policy lead to permanent effects on the long-run rate of economic growth. In his time series analysis of the US and the post-War OECD growth paths, Jones rejects this presumption, arguing that the long-run growth rate is invariant to conventional government policies. This finding suggests that the stock of knowledge may be subject to depreciation over time due to *obsolescence*. Jones (1995b; 1998) pursues this line of thought further, while Caballero and Jaffe (1993) incorporate a neo-Schumpeterian mechanism of *creative destruction* and knowledge spillovers into a model of economic growth.

Finally, Rodriguez-Clare (1996; 1997) also offer a critical review of contesting theories of endogenous growth and report data on international productivity differences. Rodriguez-Clare (1996) casts doubts, in particular, on the expected positive role of multinationals in affecting underdeveloped regions' growth performance through generation of linkages. He shows that such linkage effects on the host country are likely to be positive if (i) the good that multinationals produce uses intermediate goods intensively; (ii) when there are large costs of communication between headquarters and the production plant; and (iii) when the home and host countries are not too different in terms of the variety of intermediate goods produced. If, on the other hand, these conditions are reversed, the underdeveloped host country may be hurt, and the multinationals may end up creating enclaves among developing countries.

Clearly, the potential determinants of long-run growth are numerous and a single model, based on the experience of a selected number of countries cannot capture all of the long-run dynamics of the history of real world economies. For example, in his review of the growth experience of the East Asian countries, Stiglitz (1996) suggests that the determinants of growth are generally caused by a host of market failures that vary by *country* and by the *level of development*. This view implies that models focusing on a single or narrowly based determinant of growth are unlikely to explain the experience of a large number of countries. Keeping in mind the gulf that still appears to exist between the various theories of growth and the lack of empirical evidence to support one category of theory over another, it is nevertheless a useful benchmark to focus on a theoretical model where both the generation and diffusion of technological knowledge are based on market transactions. Given this setting, attention then can be directed on the extent to which a decentralized market economy provides adequate incentives for the accumulation of knowledge, and how variations in economic structures, institutions, and policies might translate into variations in productivity gains.

A main focus of many of the studies reviewed above is to specify a reduced form structure to estimate the extent to which a country's total factor productivity depends on domestic and global R&D capital. Whereas in our study, we cast the problem in a structural general equilibrium setting, and simulate the market transactions of private agents as optimizers in response to various market signals and government policies. In contrast to the analytical models which tend to depict economies in more aggregate and abstract terms, our model is calibrated to a fairly disaggregated data set of a ''real'' economy — Japan.

We distinguish two sets of policies: (i) those which encourage own R&D activities, and (ii) those which tend to use other countries' technology stock through R&D cross-border spillovers. Under the second set of policies, we investigate the growth effects of trade policies. Our major finding is that, from a long-run growth perspective, a selective (strategic) trade policy based on growth-promoting considerations may increase a country's welfare. Full trade liberalization results in a welfare gain in the short-run, which is consistent with the conventional static welfare arguments. However, a selective (targeted) policy that distorts trade in a special way can succeed in generating a positive effect on productivity and stimulate the long-term rate of growth with positive long-term welfare benefits. [5]

In the case of (i) above, we study the growth consequences of own R&D promotion with the aid of two instruments, a direct subsidy on R&D activities, and indirect subsidies on the use of R&D intensive inputs. We find that these policies encourage private agents to allocate more resources to domestic R&D activities, thus effectively serving as an alternative to targeted foreign trade policies that place relatively more emphases on inducing growth from technological spillovers. Also, the cost of R&D promotion policy, as a ratio to the country's GDP, falls within a range that seems feasible, especially for a large country.

Almost all of the world's R&D activity is observed to be concentrated in the industrial countries. Hence, it is more important for a developing country to take advantage of spillovers from the developed industrial countries' stock of R&D through foreign trade. In the meantime, it is equally important to encourage domestic R&D activity so that the recipient country can actually internalize such spillovers. For this reason, the choice of Japan as a successfully industrialized country which is known to have drawn upon foreign technical knowledge seems particularly appropriate.

Japan's per capita GDP was only a third of that of the US before World War II. During the period of 1965 to 1989, Japanese R&D expenditures increased at rate

[5] See Grossman and Helpman (1990) for an analytical account of this proposition.

of 8.1%, per annum (Coe and Helpman, 1995, Table A2). Three decades of rapid growth has placed Japan among the leading industrial nations with a ratio of R&D expenditures to GDP on par with that of the US. In this sense, the recent economic history of Japan provides a viable case for identifying the importance of government policies to promote a country's growth rate. However, we should emphasize that the purpose of this paper is not to calibrate the growth path of the Japanese economy, or to study the history of Japanese economic growth. Such a venture is beyond the scope of our analysis. [6] Rather, based on the endogenous growth theory and given plausible parameter values, our policy simulation experiments are designed to quantitatively investigate the importance and mechanisms of alternative government policies in affecting a country's long-run growth rate.

The plan of the paper is as follows: in Section 2, we present the structure of the R&D-driven endogenous growth general equilibrium model; followed by a description of the model's data sources and the calibration method in Section 3. Section 4 reports and analyzes results of our empirical policy simulations. Section 5 summarizes and concludes.

2. The model structure

The model is a direct application of the R&D-driven endogenous growth theory and is presented in five sub-sections, starting with the final output production, concluding with the condition for equilibrium. The use of equations is kept to a minimum as the model appears in its entirety in Appendix A.

2.1. The final output production sectors

The economy is presumed to be open, and its trade partners are aggregated into three countries/regions: US, EU and the Rest of the World. The economy operates with seven final output production sectors: (1) agriculture and minerals, (2) intermediate materials, (3) textiles, (4) transportation equipment, (5) other machinery equipment, (6) other manufacturing, and (7) services. With constant returns to scale technology, each sector produces a single output using inputs of labor (L), scientists/engineers (G), a non-human resource (B), and a set of differentiated capital and other intermediates. To focus on the study of technological progress through R&D activities, and economic growth through productivity,

[6] A comprehensive account of the history of Japanese economic development is given by Morishima (1982), Ohkawa and Kohama (1989) and Ito (1992). See also the works of Westphal and Kim (1982), Kwon (1986), Amsden (1989) and Stiglitz (1996) for a controversial assessment of the East Asian patterns of development.

the supplies of labor, scientists/engineers and non-human resources are held constant over time. Differentiated capital is augmented by creating more new varieties. A given variety of capital is assumed to substitute imperfectly for another variety according to a constant elasticity of substitution (ε). All production factors are perfectly mobile in the economy, but immobile internationally. Firms producing final outputs face perfectly competitive output and input markets.

Outputs of the seven sectors are demanded in several different ways. They serve as intermediate inputs of production in each of the seven sectors; they meet the demands for final goods by households and the export demands of the foreign sector; and they are employed in investment — to produce differentiated capital varieties.

2.2. Differentiated capital, R&D, and their production

Growth is traditionally associated with capital accumulation. However, as Stiglitz (1996) notes, ''if life consisted of nothing more than adding homogeneous capital to a homogeneous production process'', it would be hard to observe any significant deviation from a given historical growth path for the world. Rather, capital is modeled here as a heterogeneous input which accumulates by increasing the number of varieties, $k(I)$, where I is the index for one type of capital variety.

Each variety of heterogenous capital is developed and produced by an individual firm. To develop and produce a new capital variety, the firm must engage in research and technical development which results in a new design or blueprint. The expenditure on the R&D is an initial up-front cost for the firm, a cost which is independent of the quantity of capital variety it produces later. As the R&D costs are not included in the marginal cost of capital variety production, we assume the existence of a legal system to protect firms' property rights to the outcome or inventions resulting from their R&D activities. This assumption precludes other firms from producing a capital variety identical to that of another firm which, together with the imperfect substitutability among varieties in the production of final goods, provides the firm with monopoly power in determining the rental price charged to producers of final goods. If the property right cannot be enforced, then other firms could compete away the monopoly rents accruing to the new idea, leaving investors with no incentive to incur the up-front cost of developing a new idea.

To conduct R&D, the monopoly firms need to employ the three primary factors, while to build new capital varieties, they need to use forgone final outputs of the seven production sectors. As each capital variety is produced by a single firm, to simplify the analysis, we assume that all monopoly firms are symmetrical, i.e., they have identical R&D production technology as well as the technology to build capital varieties. Furthermore, each firm employs the same quantities of primary inputs in R&D activity and produces the same volume of capital variety. Thus, each capital variety bears the same price to producers of final goods.

As all monopoly firms in the capital good sector share an identical technology in conducting R&D activities, we can derive an aggregate R&D production as follows:

$$\Delta M(t) = A_{\mathrm{m}}(t) M(t) L_{\mathrm{m}}^{\theta_1} G_{\mathrm{m}}^{\theta_2} B_{\mathrm{m}}^{\theta_3} \tag{1}$$

where $\Delta M(t)$ is new ideas/blueprints produced at one time period in the economy, while $M(t)$ is the stock of the common knowledge; $A_{\mathrm{m}}(t)$ denotes the productivity coefficient further defined below. L_{m}, G_{m} and B_{m} are, respectively, the inputs of labor, scientists/engineers and non-human resources; and $\sum \theta_i = 1$, i.e., the technology exhibits constant returns to scale in individual firm's employment of the primary inputs. However, once an idea is embodied in an investment project, the spillover effects occur. Such spillovers enlarge the pool of common technological knowledge, M, which enters the R&D production function as an externality to raise productivity. The common knowledge, M, accumulated from the past R&D activities is assumed to be proportional to the cumulative output of each individual firm's R&D activities. In other words, the R&D activities conducted by the investment firms for purposes of maximizing monopoly profits also generate spillovers to expand the common pool of technological knowledge in the economy and hence, augment the productivity of the entire R&D sector.

In this model, spillover effects not only occur among domestic investment firms, but also originate from foreign countries. Measures of cross-border technological spillovers vary in the literature. Based on some econometric findings (e.g., Coe et al., 1997; Wang and Xu, 1997), the cross-border spillovers are assumed to be generated through the imports of investment goods. These spillovers are modeled to further augment the productivity of the domestic R&D activity. This specification allows us to link foreign countries' technological knowledge with domestic R&D activities. While international trade is considered as a ''carrier'' for transmitting the spillovers, the existence of a well-established system of domestic R&D activities determines the ''absorptive capacity'' of the country to realize such technological spillovers. In formal terms, the productivity coefficient, A_{m}, in Eq. (1) is a function of cross-border spillovers, which are denoted as ζ. Following C&H, the spillover coefficient, ζ, is recognized as a function of the import-weighted pool of foreign technological knowledge (which are proportional to their R&D stocks) and the elasticities of the home country's R&D productivity with respect to foreign R&D stocks, ξ, i.e.,

$$\zeta = \xi \sum_r \omega_r M_r \tag{2}$$

Where ω_r is the share of investment good imports from country r; and M_r is the stock of R&D in country r. To ensure convergence to the steady-state, we further assume that A_{m} is linear in ζ, i.e.,

$$A_{\mathrm{m}}(t) = (1 + \zeta(t)) \bar{A}_{\mathrm{m}} \tag{3}$$

where $\bar{A}_{\mathrm{m}}$ is the initial level of technological coefficient in the R&D production function.

The number of new capital varieties produced at time period t is equal to the number of new ideas/blueprints produced at the same period, $\Delta M(t)$. Ignoring depreciation, the number of accumulated capital varieties in the economy at time period t is equal to the number of blueprints available in the economy. When the number of blueprints increases, the number of capital varieties expands as well, leading to capital accumulation.

The technology for producing capital variety is presumed to exhibit constant returns to scale. Thus, unit material cost of a capital variety is a function of the final output prices, and is assumed to be the same for each producer of differentiated capital:

$$\mathrm{MC}_k = \prod_{j=1} \left(P_j / \eta_j \right)^{\eta_j}$$

where MC_k is per unit material cost of each capital variety produced; P_j is the price of good j employed in the investment process, $j = 1,2,\ldots,7$; and η_j is the expenditure share of that good.

The employers of capital variety (final good producers) pay a capital rental price higher than the unit material cost multiplied by the interest rate due to the monopoly power of investors. This monopoly rental price depends on the substitution elasticity of demand for capital variety. This well-known mark-up price is: $P_k = r\mathrm{MC}_k/\delta$, where $\delta = 1 - 1/\varepsilon$, and ε is the substitution elasticity of demand among the differentiated capital varieties.

The monopoly firms have a forward-looking behavior. That is, they make investment decisions on developing new blueprints and producing new capital varieties so as to maximize the long-run expected returns from an infinite stream of monopoly revenues. In particular, the expected returns from investment must be comparable with those from holding a 'safe' asset such as bonds or bank deposits. Thus, asset market equilibrium requires, for any point in time, that the following non-arbitrage condition must hold:

$$P_{k(i)} k(i) + \Delta V(i) = rV(i)$$

for firms producing capital variety, where $P_{k(i)}$ is the monopoly capital rental price for $k(i)$. Thus, $P_{k(i)} k(i)$ is the total revenue of the monopoly investor i in any given time period. $V(i)$ is the value of the ith firm, and r is the interest rate on the safe asset. The term $\Delta V(i)$ denotes changes in the value of the ith firm with respect to time. In equilibrium, the value of the firm is equal to aggregate investment expenditures of this firm, which includes the cost of developing a new blueprint ($P_{\mathrm{R\&D}}$), plus the material costs of investment goods ($\mathrm{MC}_{k(i)} k(i)$). Imposition of the transversality condition to rule out speculative bubbles gives:

$$V_n(i) = \sum_{t=n}^{\infty} R(t) \left[P_{k(i)_t} k_t(i) \right]$$

that is, the value of the monopoly firm is equal to the discounted value of the stream of monopoly revenues, where $R(t)$ is a discount factor defined according to:

$$R(t) = \prod_{s=n}^{t} (1 + r_s)^{-1}$$

As all produced capital goods bear the same rental price, final good producers employ equal quantities $k(i) = k$ of each.

2.3. The household

All primary factors and the equity of the monopoly firms are owned by a representative household. The household has perfect foresight and exhibits forward-looking behavior. Aggregate consumption and savings are derived from an intertemporal utility maximization behavior. Thus, in each time t, the household maximizes:

$$U_s = \sum_{t=s}^{\infty} (1 + \rho)^{-t} \frac{\mathrm{TC}_t^{1-\sigma} - 1}{1 - \sigma}$$

subject to the wealth constraint:

$$\sum_{t=s}^{\infty} R(t) \mathrm{PC}_t \mathrm{TC}_t = \mathrm{TW}_s$$

where ρ is the rate of time preference; σ is the inverse of the intertemporal elasticity of substitution; TC is an index of overall consumption; PC_t is the shadow price for the overall consumption; and TW_s is total wealth which includes the present value of returns to primary factors and the value of monopoly firms.

In each period, the household's income flows include primary factor incomes, capital rental income of the monopolistic firms, and government transfers. [7] The current budget constraint for the household is:

$$\mathrm{SAV} = W_L L + W_G G + W_B B + P_k(Mk) - \mathrm{PCTC} + \mathrm{TR}$$

where SAV is household savings, W_L, W_G and W_B are unit price for the primary factor L, G, and B, respectively, M is the number of differentiated capital, and TR is net government transfers.

From this intertemporal utility maximization problem, a sequence of overall consumption and savings can be determined. TC is a composite of seven specific

[7] The government consumption and investment are ignored in the model. All government tax revenues are transferred to the household lump-sum.

goods according to fixed expenditure shares, and its shadow price, PC, is determined by the individual good prices, according to:

$$\mathrm{PC} = \prod_{j=1} \left(P_j / \gamma_j \right)^{\gamma_j}$$

where γ_j is the expenditure share of good j.

2.4. The foreign sector

All final products can be traded. Foreign countries' demand for each good produced in the home country is aggregated and derived from a constant elasticity of transformation function (a CET function), while imported goods are country source-specific and are considered to be imperfect substitutes in consumption for the domestically produced goods. To capture the more important role of imports from industrial countries in the technological spillovers, foreign countries are aggregated into three regions: US, EU and the Rest of World. The home country's demanders of final goods choose domestic and foreign goods into each composite at minimum cost according to a constant elasticity substitution function (an Armington function).

The economy has balanced trade in each time period, with the interest rate being determined endogenously.

2.5. Equilibrium

Intratemporal equilibrium requires that at each time period: (1) demand for primary factors (L, G and B) equal their supply; (2) domestic demand plus export demand for the output of each sector equal its supply; (3) the output of R&D, the number of new blueprints, equal the number of new capital varieties invested; (4) household savings equal investment — costs of new blueprints plus costs of investment goods in capital variety production; (5) the value of total exports equal the value of total imports. In the steady-state equilibrium, all quantity variables grow at a constant growth rate which is proportional to the growth rate of R&D output (the growth rate of the number of blueprints). Since the supply of primary factors are fixed, their prices grow at the same constant growth rate. All other endogenous prices, including prices for final goods produced and consumed domestically, the unit cost of the R&D output, the rental rate for differential capital, and the interest rate are constant in the steady-state.

3. The data and the calibration strategies

The data related to the initial period's equilibrium are drawn primarily from the Global Trade Analysis Project (GTAP) 1992 data base (Hertel and Tsigas, 1995), with necessary adjustments to obtain a balanced current account. As the GTAP data are originally in the form of annual flow values and primarily compiled for the purpose of static general equilibrium analyses, they need to be further augmented by information associated with the countries' growth path, namely, capital stock, technological knowledge stock, R&D expenditure, growth rate, interest rate, and the discount rate in the intertemporal utility.

The intertemporal elasticity of substitution, $1/\sigma$, in the household utility function is chosen in the range estimated by Hall (1988). The rate of time preference, ρ, is obtained from Lucas (1988). The average growth rate of TFP between 1971 and 1990 for Japan (reported in C&H) is chosen as the growth rate for R&D and, hence, as the initial steady-state growth rate, g_0, for the economy. The initial interest rate, r_0, then has to be calculated in a way consistent with the choices of σ, ρ and g_0 (see Eq. (A32) in Appendix A). [8] We further assume that the depreciation rate of capital varieties is zero.

The data on Japan's professional personnel occupation categories are used to adjust the original GTAP data for the labor inputs. Data on the total returns to capital in the benchmark are provided by the GTAP database. We distinguish the returns to the differentiated capital from the returns to the non-human resource based on these data. This is accomplished using the calibration restrictions implied by the model. For this purpose, we have to obtain the value of the R&D output $(P_{\mathrm{R\&D}}\Delta M_0)$ first. The R&D output (ΔM), however, is difficult to measure for an actual economy. Hence, we use the ratio of Japan's R&D expenditure in its GDP as a proxy to obtain the initial year's value of the R&D output and normalize the initial stock of the R&D output (M_0) to one. Then, the number of the new blueprints produced in the benchmark is equal to the growth rate, as $g_0 = \Delta M_0/M_0$ (see Eq. (A31)). Also, as most scientists and engineers are more or less involved in R&D activities, we assume the R&D is high scientist/engineer intensive and uses a major portion of this factor.

To calculate the initial level of the cross-border spillover coefficient function, we use the value of R&D capital stocks in US and EU in C&H, weighted by the shares of investment good imported by Japan from these regions in the GTAP data. As almost, the entire R&D activity in the world economy is concentrated in the industrial countries [9] (UNESCO, 1993, 1995), the value of R&D stocks in the Rest of World (one of the regions in the model as a trade partner of Japan) is chosen as 10% of the world R&D stocks in the model. Since, for calibration

[8] As in static applied GE models, where calibration is based on the assumption that data reflect an economy in equilibrium, we assume that the benchmark data depict an initial steady-state growth path. This steady-state assumption for the benchmark data is widely used in applied intertemporal general equilibrium models (for example, Goulder and Summers, 1989; Go, 1994; Diao et al., 1996, 1999; Mercenier and Yeldan, 1997).

[9] For example, in 1990, the industrial countries accounted for 96% of total world R&D expenditures. Within OECD the seven largest economies account for 92% of R&D in 1991 (Coe et al., 1997).

purposes, Japan's benchmark R&D stock is normalized to one, the values of its trade partners' domestic R&D capital stock are normalized by the value of Japan's R&D stock in C&H (1995). The R&D productivity elasticity, ξ, with respect to foreign R&D stock in Eq. (2) is chosen at the level such that the benchmark value of spillover coefficient, ζ_0, in Eq. (3) has a value which can be comparable with the ratio of estimated TFP elasticities with respect to foreign R&D stock to own R&D stock for the seven largest OECD countries in C&H. The estimated TFP elasticities with respect to R&D stock vary in literature. For different spillover elasticities, the simulation outcomes may be different. For this reason, we choose the initial value of spillover coefficient, ζ_0, with two different levels of spillover elasticities, ξ, i.e., the high and low levels. We compare the simulation outcomes corresponding to these two different elasticities.

To ensure the existence of a balanced growth path, share parameters for the differentiated capital, α_k, in the value added functions have to be the same for all sectors. Based on this steady-state restriction, and further assuming $\delta = \alpha_k$ for simplification, we calibrate α_k and the total investment, including the value of

Table 1
Benchmark values for selected variables and parameters

Variables or parameters	Values
Share of rental value of differentiated capital in GDP (α_k)	0.17
Share of scientist/engineer in R&D (θ_G)	0.50
in agriculture ($\alpha_{A,G}$)	0.00
in transportation equipment ($\alpha_{T,G}$)	0.12
in other machinery equipment ($\alpha_{M,G}$)	0.13
Share of non-human resource in R&D (θ_B)	0.45
in agriculture ($\alpha_{A,B}$)	0.30
in transportation equipment ($\alpha_{T,B}$)	0.22
in other machinery equipment ($\alpha_{M,B}$)	0.26
Share of labor in R&D (θ_L)	0.05
Agriculture ($\alpha_{A,L}$)	0.53
Transportation equipment ($\alpha_{T,L}$)	0.49
Other machinery equipment ($\alpha_{M,L}$)	0.44
Share of R&D expenditure in GDP ($P_{R\&D0}\Delta M$)	0.05
Value of spillover coefficient	0.44 (high); 0.1 (low)
Growth rate (g_0)	0.0285
Interest rate (r_0)	0.069
Inverse of the intertemporal elasticity of substitution (σ)	1.51
Subjective time discount rate (ρ)	0.025
Monopoly profits (π_0)	444,743
Marginal cost of capital investment (MC_k)	2.43
Value of the differentiated capital stock (Mk_0)	534,961
Value of labor supply (L_0)	149,781
Value of scientist/engineer supply (G_0)	37,792
Value of non-human resource supply (B_0)	761,459

R&D output $(P_{R\&D}\Delta M)$ and the cost of new capital variety production $(MC_k \Delta Mk_0)$, simultaneously (see Eqs. (A38) and (A39)). Once the value of investment is specified, we obtain the value of the cost of new capital varieties $(MC_k \Delta Mk_0)$ by subtracting the value of the R&D output $(P_{R\&D}\Delta M_0)$ from the value of total investment (see Eq. (A37)). To separate the marginal cost of capital (MC_k) and the quantity of capital (k_0), we normalize the capital rental price (P_k) to unity. As P_k is a mark-up price, MC_k can be derived from $MC_{k0} = \alpha_k P_{k0}/r_0$ (see Eq. (A7)). Thus, k_0 and the stock of total capital varieties are obtained from $MC_k \Delta Mk_0$ (recall that the total number of new blueprints (M_0) is normalized to one and $\Delta M = g_0$). Table 1 presents the initial levels of selected variables and parameters obtained from sources other than the main data base or from this calibration process.

4. Policy analysis

We now utilize the model to study issues of strategic trade policies and R&D promotion policies. We first consider how trade policy affects domestic R&D production as well as the use of global technological stock through R&D cross-border spillovers. The GTAP data on Japanese foreign trade reveal different protection rates among the seven sectors. Tariff rates protecting the three manufacturing sectors are very low, in the range of 1–3%, while in the case of agriculture, the tariff plus the non-tariff equivalent protection rate is quite high. The rate of protection is 106 and 82% for agricultural imports from US and EU, respectively, and averages about 42% overall. Given these facts, the question is whether the current trade policy or any alternative policy is preferred for the purpose of long-term growth. We assess this question by conducting three experiments: (a) liberalizing agricultural trade by eliminating all tariff and non-tariff protection on agricultural imports; (b) protecting manufacture by arbitrarily imposing a 50% tariff rate on manufacturing imports and removing agricultural protection completely; and (c) further intensifying trade protection in agriculture by arbitrarily raising the tariff rate on agricultural imports by 50%, while maintaining the open stance of the rest of the economy as indicated in the initial data. In fact, since Japanese agriculture is highly protected in the benchmark data and protection rates for the non-agricultural sectors are relatively low, the first scenario is equivalent to a full trade liberalization scenario for Japan. We report the simulation results for both the transitional equilibria and the new steady-state. Transitional dynamics are derived from the time discrete model over an interval of 150 years, with each equilibria spaced 1 year apart.

4.1. Effects of trade policies on growth

Major findings from our experiments are that trade policy affects long-run growth mainly through its effects on cross-border technological spillovers, while its effects on growth through change in domestic R&D activity are quite small. The main reason is that, even though different trade policies affect the allocation of resources among sectors producing final goods, resources which are ultimately re-allocated to the R&D activities by such policies are modest. Furthermore, concomitant with its role as a carrier of cross-border spillovers, trade liberalization among different sectors affects growth differentially. A strategic trade policy, biased towards more open trade in investment goods, allows the country to take greater advantage of foreign R&D, and hence, leads to larger welfare gains in the long-run.

4.1.1. Resource re-allocation effects of trade policies on growth

R&D activity competes for resources with the final output sectors. Thus, if trade policies result in the protection of a final output sector which also competes with the factor used most intensively in the R&D activity, then resources are diverted to the final good sector and away from R&D production. Since the rate of accumulation of knowledge through advances in R&D production is the ultimate source of growth in this economy, the overall rate of growth slows down, despite possible short-run increases in the rate of growth of some sectors in response to re-allocation of resources. In contrast, if the sector which competes for resources with the R&D production were liberalized, and the tariff protection is imposed on the sector(s) which does not share the factor intensity of the R&D activities, then the ongoing trade policy would indirectly create conditions favorable to R&D production. Hence, the overall rate of growth is stimulated.

All these results, in fact, depend critically on the Stolper–Samuelson-like effects on the relative rental rates of primary resources. R&D production is not only regarded as scientist/engineer (S&E) intensive, but also it is the major employer of this resource in the economy. Yet, S&E is also employed by the final good producing sectors, especially by the three manufacturing sectors. Under the agricultural trade liberalization scenario, the manufacturing sectors benefit from an increase in their real prices, relative to that of agriculture. An increase in manufacturing output implies an increase in the employment of S&E in these sectors. Thus, the manufacturing sectors ‘‘pull’’ S&E personnel away from the R&D activities. However, this implies that the long-run effects of the agricultural liberalization policy have adverse consequences on the production of new blueprints.

Furthermore, the investment decision of the monopoly firms are also affected by the trade policy. Given other costs, if the monopoly profits fall relatively to the initial R&D expenditures, investment in developing and producing new capital varieties decline. Under the agricultural trade liberalization scenario, monopoly profits relative to the initial R&D expenditure fall by 2.6%. The main reason is that, as the relative prices of the manufacturing products increase, the material costs of capital investment also increase. In addition, the initial or up-front R&D costs rise as the relative price of S&E rises (Table 3, column 1).

Nevertheless, the net effect of this increased competition for the resource used intensively in the R&D activities on the long-term growth of the economy is relatively small. By ignoring the cross-border spillover effect, we observe that under the agricultural trade liberalization scenario, resource re-allocation leads to the decline of the growth rate by only 0.015 percentage point (Table 2, column 1, Fig. 1a). Such small growth effects are mainly the result of the comparably little impact of tariffs on relative factor prices. For example, under the agricultural trade liberalization scenario, the producer prices for the three manufacturing sectors rise by more than 4%, whereas the change in the relative prices of the primary factors is less than 1% (Table 3, column 1). Given such a small change in the relative prices of the primary inputs, the adjustment in the input use of the R&D activity is quite small.

4.1.2. Cross-border spillover effects of trade policies on growth

In contrast to the above discussion, the cross-border technological spillovers are significantly affected by the presumed trade policies. For example, in the agricultural trade liberalization scenario which caused growth rate to slow by only 0.015% in the absence of cross-border spillovers, the long-run growth rate is lowered by 0.17 percentage points, once the cross-border spillovers are taken into account (Fig. 2a). Parallel to our results originating from resource re-allocation effects, trade liberalization does not necessarily imply a faster long-run growth rate

Table 2
Long-term growth rate, interest rate and welfare index under different policy scenarios (%)

	Without spillovers	High elasticity[a]	Low elasticity[b]
Growth rate			
Benchmark	2.85	2.85	2.85
Liberalizing agricultural trade	2.835	2.678	2.789
50% tariffs on manufacturing	2.834	1.996	2.585
Further protecting agricultural trade[c]	2.854	3.066	2.917
6% R&D subsidy	3.0677	3.0688	3.0680
6% differentiated capital subsidy	3.0676	3.0689	3.0680
Welfare index[d]			
Liberalizing agricultural trade	−0.95	−20.65	−7.27
50% tariffs on manufacturing	−1.22	−69.93	−30.62
Further protecting agricultural trade[c]	0.16	35.26	9.52
6% R&D subsidy	35.67	35.86	35.73
6% differentiated capital subsidy	36.72	36.97	36.79

[a,b] The high and low spillover elasticities are chosen such that the value of the benchmark spillover coefficient is 0.44 vs. 0.1.
[c] Raising tariff rate on the agricultural imports by 50%.
[d] Welfare index is the equivalent variation defined in Appendix A.

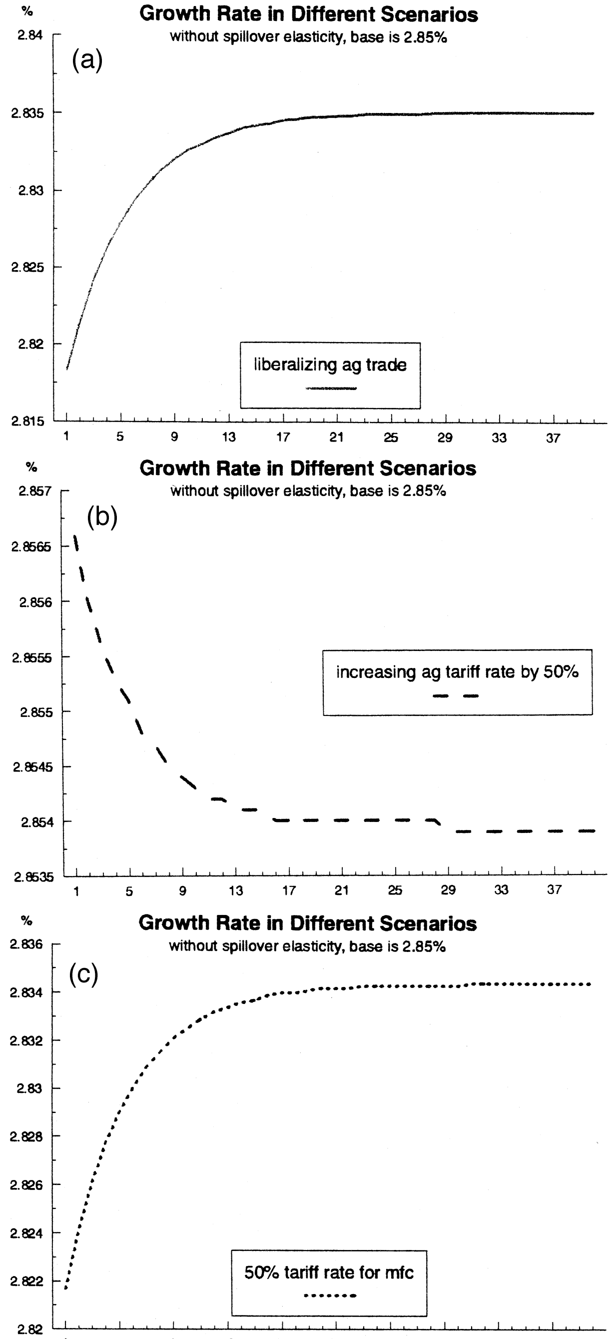

Fig. 1. (a–c) Growth rate in different scenarios without spillover elasticity; base is 2.85%.

Table 3
Effects of liberalizing agricultural trade experiment on selected variables in the first year and in the steady-states[a] (% change from the benchmark data with benchmark growth rate)

	Without cross-border spillovers		With cross-border spillovers and high elasticity	
	Year 1	Steady-state	Year 1	Steady-state
Unit cost of R&D ($P_{R\&D}$)	−0.58	−0.31	3.13	4.24
Monopoly profits (π)	−0.82	−0.64	−0.49	0.20
$\pi / P_{R\&D}$	−0.24	−0.34	−3.58	−3.78
W_G / W_L[b]	0.99	1.12	0.28	0.73
Producer price[c]				
Agriculture	−3.96	−3.97	−3.93	−3.95
Transportation equipment	0.62	0.62	0.62	0.62
Other machinery equipment	0.68	0.68	0.67	0.67
G[d] demanded by R&D	−1.964	−1.301	−4.10	−2.43
G demanded by manufacturing	12.798	12.601		
Share of machinery imports				
From US			−7.94	−8.03
From EU			−10.53	−10.59

[a]All variables in this table are constant in the steady-states.
[b]W_G is wage rate for G and W_L is wage rate for L.
[c]Output prices are normalized by the current year output price index.
[d]G is scientist/engineer input.

for the economy. On the contrary, we find that under the high spillover elasticity specification, the rate of growth falls throughout the transitional path, and falls to 2.68% in the new steady-state (Table 2, column 2), in comparison to the 2.85% long-run growth rate of the benchmark data.

Here, the reason for the deceleration of the rate of growth is the decline in the share of investment good imports. Once the supply of manufacturing production rises following the elimination of agricultural protection, an increased portion of aggregate demand for manufacturing goods is now met by the domestic supply, and import demand for the respective goods falls. Under the agricultural trade liberalization scenario, the import shares of investment goods from the US and the EU fall by about 10% (Table 3, column 3). Given the spillover elasticity and foreign R&D stocks, with a lower share of investment good imports, the home country benefits less from the global technical knowledge embodied in foreign investment goods. The rate of domestic R&D productivity slows down, and so does the long-run rate of growth.

To further illustrate the effects of a *selective* trade policy on the rate of growth, we design two additional scenarios: (1) trade protection on the three manufacturing sectors are arbitrarily increased by the imposition of a 50% ad valorem tariff, while agricultural protection is eliminated, and (2) tariff rate on the agricultural

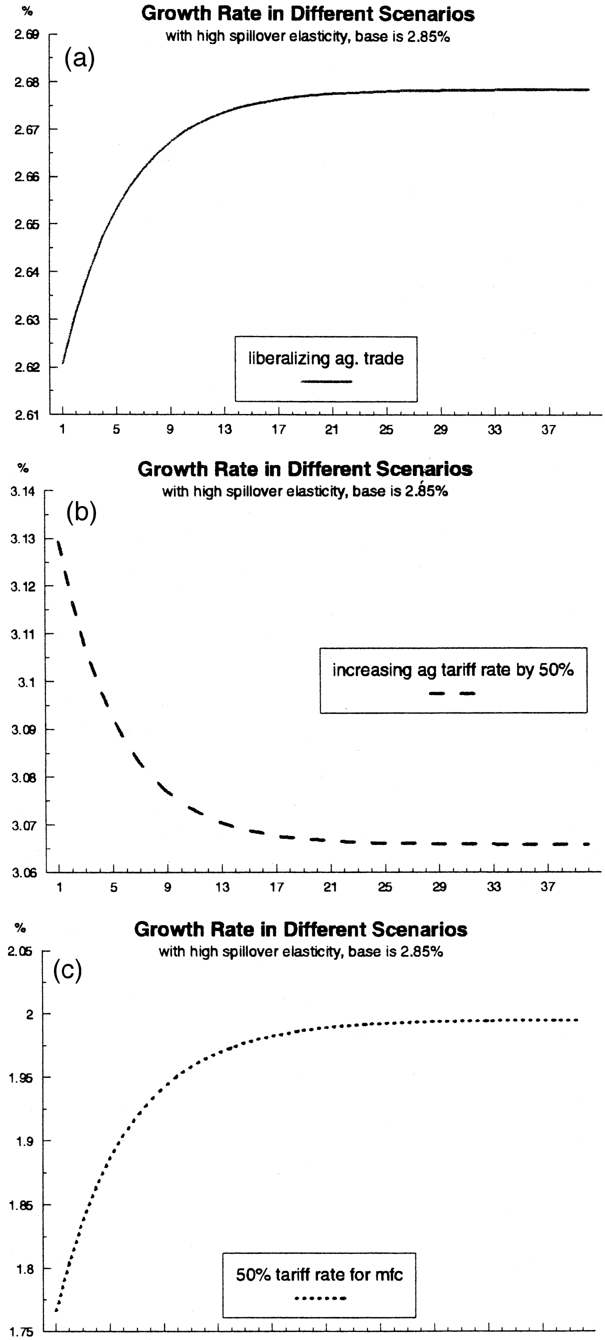

Fig. 2. (a–c) Growth rate in different scenarios with high spillover elasticity; base is 2.85%.

imports is arbitrarily increased by 50% while the tariff rates on the other sectors are kept at the initial levels given in the data. Revenues of the increased tariffs are transferred to the household lump-sum. The first scenario can be seen as a reflection of the trade distortionary import-substitution policies pursued by many developing countries during the 1960s and 1970s, while the second scenario is administered to emphasize the consequences of a selective, ''strategic'' trade policy on long-run growth. In the first simulation, the model results reveal a significant decline in the growth rate both along transition and in the steady-state (the steady-state growth rate falls to 1.99% from its benchmark rate of 2.85%, Table 2, column 2, Fig. 2c), while in the second simulation, the growth rate rises to 3.06% (Table 2, column 2, Fig. 2b).

These results suggest that a strategic trade policy for a country's long-run growth should be targeted towards better utilization of foreign R&D capital stock and the generation of larger cross-border technological spillovers. As R&D knowledge spillovers are carried by investment good imports, a policy which is biased towards more open trade in investment goods would lead to a superior growth performance. It is well-known that countries such as Japan and Korea, which were able to sustain high economic growth rates for more than 30 years, have been restricting their agricultural trade and simultaneously promoting manufacturing trade. Of course, the designation of such policies were based on many political and economic considerations other than growth, nevertheless, such policies would also seem to enhance their long-run rate of economic growth.

Clearly, the quantitative nature of these results depends crucially on the size of the spillover elasticities. For instance, under the agricultural trade liberalization scenario, with a lower value of spillover elasticity, the negative effects on the long-run growth rate become smaller: instead of a 2.678% rate of steady-state growth in the case of high spillover elasticity, it becomes 2.789% (Table 2, column 3, Fig. 3a), while the benchmark rate is 2.85%. Under the second scenario in which import tariff rates of the manufacturing sectors are increased to 50%, the steady-state growth rate falls to 2.585% with the low elasticity, and falls to 1.996% with the high elasticity (Table 2 and Fig. 3c).

It has to be noted, however, that our evaluation of the effects of different levels of cross-border spillover elasticities is not only for purposes of sensitivity testing. Differences of spillover elasticities reported in empirical studies are also a reflection of the different levels of economic development. In general, we would expect the productivity elasticity with respect to foreign R&D capital stock to be larger for developing countries which invested little in R&D than for those large developed countries which invest heavily, and account for almost the entire R&D activity of the world. For example, in C&H, the ratio of TFP elasticity with respect to foreign R&D stock to the elasticity with respect to domestic R&D stock in the group of the seven largest OECD countries is found to be much higher than that in the group of all OECD countries (Table 3, p. 869). Thus, the ''low'' level of the cross-border elasticity scenario may be more suitable for large

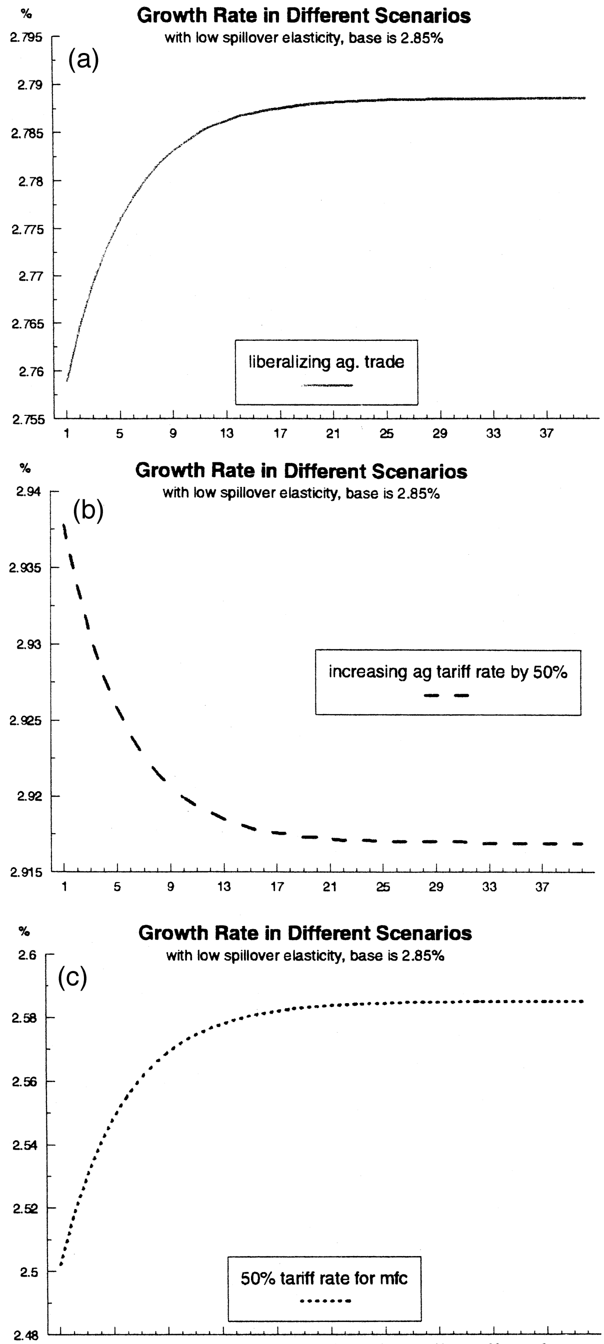

Fig. 3. (a–c) Growth rate in different scenarios with low spillover elasticity; base is 2.85%.

industrial countries, while the ''high'' elasticity scenario is likely to be more appropriate for countries that are in the initial stages of industrialization. [10]

4.1.3. Long-run welfare effects

We analyze the social welfare consequences of the policy simulations by the equivalent variation index used in the work of Mercenier and Yeldan (1997). This index is derived from the intertemporal utility function which accounts for multi-period felicity effects (see Eq. (A34)). We find that under the trade liberalization scenario, the welfare indices change sign during the course of adjustment toward the steady-state. With a high spillover elasticity, welfare rises during the earlier period of transition to the steady-state. Gains of 1.1, 0.88 and 0.25% are obtained for the first 1, 5, and 10 years, respectively. However, with the time horizon being extended, e.g., to year 15, we observe a welfare *loss* of 0.5%. If the welfare effects on the steady-state path are also taken into account, the overall welfare loss increases to more than 20% (Table 2, column 2). With a low spillover elasticity, the welfare indicator for the first 24 years turns positive, while the welfare loss for the whole path, including the path in the steady-state reduces to 7% (Table 2, column 3).

The results on the welfare effects of the trade liberalization during early periods along the transition are consistent with the conventional static welfare arguments that free trade is the first best policy, while distorted trade is always linked with welfare losses. That is, in the short-run, efficiency gains from resource re-allocation play a dominant role in determining the welfare outcomes. However, in a relatively longer time period, when positive externalities from technological spillovers are taken into account, the welfare consequences of a trade policy are mainly determined by the long-run growth effects. These results imply that if a selective trade policy can generate a significantly positive effect on the improvement of productivity and hence succeed in stimulating the rate of growth, its welfare effects in the long-run may not be consistent with the effects in the short-run, as a static welfare argument would suggest.

4.2. Effects of R&D promoting policies on growth

In the context of this model, technical knowledge has two properties. It is ''non-rival'' in the sense that its use by one does not preclude its use by others, and it is ''partially excludable'' in the sense that a producer of differential capital obtains the property right to a blueprint at a cost that is less than its true marginal

[10] However, in the less developed economies with only a nascent manufacturing sector, imports of manufacturing goods are mainly consumed as final goods, and hence, are unlikely to generate any R&D spillover of the nature considered here.

value. That is, while another producer of differentiated capital cannot appropriate the blueprint due to the property right, it nevertheless represents an increase in the stock of knowledge which leads, incrementally, to more efficient production of blueprints. However, the owner of the blueprint is unable to appropriate these additional returns. Consequently, the owner can only earn the monopoly profits to cover the initial expenditure on blueprint production. The second market failure is more conventional: imperfect competition in the production of differentiated capital tends to lower the scale of output of each variety of capital. In the absence of public intervention, these market failures are likely to induce agents to under-invest in the provision and acquisition of new technologies. The correction of these failures can, in principle, lead to Pareto superior outcomes.

To explore these basic mechanisms, we investigate two policy instruments, each of which promotes growth by encouraging domestic private R&D activity. One instrument is an ad valorem subsidy to the cost of inputs employed by producers of R&D. The other is an ad valorem rental price subsidy to the employers of differentiated capital. A subsidy to producers of R&D output encourages them to bid primary resources away from other sectors. The second policy is based on the consideration that employers of differentiated capital pay a rental price that exceeds its marginal product. A subsidy to the employers of differentiated capital increases its demand, thereby providing incentives to increase the production of differentiated capital due to rising rents, which in turn increases the number of new producers of differentiated capital and the production of blueprints.

For each policy instrument, the subsidy rate is chosen at the level to reach the long-run growth rate of the third trade policy scenario (i.e., increasing the agricultural tariff rate by 50% along with a high spillover elasticity). Our motivation here is to study as to what extent a ''strategic'' trade policy can be a substitute for policies directly promoting domestic R&D. Given our results in Section 4.1 above, we find that a strategic trade policy which further encourages manufacturing imports by, for example, increasing the protection afforded agriculture, can succeed in increasing the long-run rate of growth. From this simulation, one can determine the level of R&D subsidy necessary to achieve a comparable rate of growth, and whether the burden of the costs of such targeted subsidization would be manageable and at par with the endowments of the fiscal authority. [11]

Even though selective trade policy can succeed in stimulating growth, the associated rate of trade protection rate may be unrealistically high. This implies that to enhance long-run growth, it may be virtually impossible to rely only on selective trade policies. An R&D subsidy, on the other hand, has usually less distortionary effects on the economy. Yet, the question is whether the fiscal

[11] We are grateful to an anonymous referee for bringing this issue to our attention.

incidence of the subsidy is within an ''acceptable'' range. We find from R&D subsidy scenarios that a relatively low subsidy rate can generate a similar outcome to that observed in the third target trade scenario. The model result shows that, to reach a 3.07% long-run growth rate, the subsidy is equivalent to 6% of total R&D production costs. The subsidy is financed by a lump-sum tax on household income. The cost of the R&D subsidy policies, as a ratio of gross domestic product, is found to be quite modest. In the case of the 6% R&D subsidy, the lump-sum tax is calculated to be equivalent to 0.3% of the country's GDP. Similarly, to finance the 6% subsidy to employers of differentiated capital, the lump-sum tax is equivalent to 0.8% of the GDP (Figs. 4–6).

Even though these results are sensitive to the numerical specification of the model's technical parameters, and, to some extent, on a host of characteristic features of the Japanese economy, they are directly comparable with many studies on the technology policies which found a much higher rate of return on investment in R&D than that on investment in, e.g., structures, machines and equipment (see Griliches, 1994, for a recent review). These results also suggest that different R&D policy instruments are not sensitive to the choice of the spillover elasticities and can have almost the same long-term effect on the production of R&D, and hence, a similar steady-state rate of growth, even though their respective transition paths vary as the instruments induce a fairly different resource adjustment among sectors, as we discuss in further detail below.

4.2.1. Adjustments induced by subsidizing domestic R&D activity

The R&D cost-subsidies induce a relatively large re-allocation of primary resources, the major adjustment of which mostly occur in the first year. Initially, the three primary factors employed by the R&D sector increase by 8–10%. After

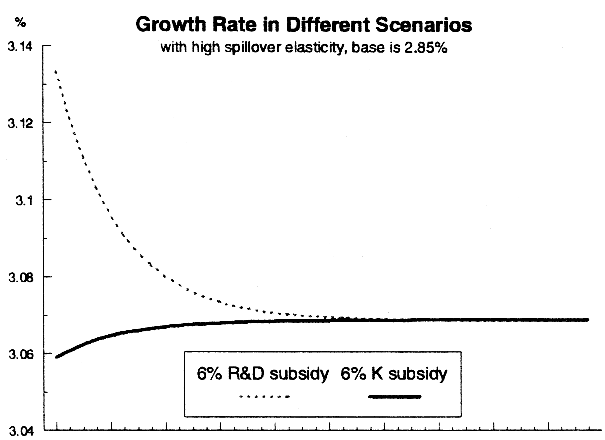

Fig. 4. Growth rate in different scenarios with high spillover elasticity; base is 2.85%.

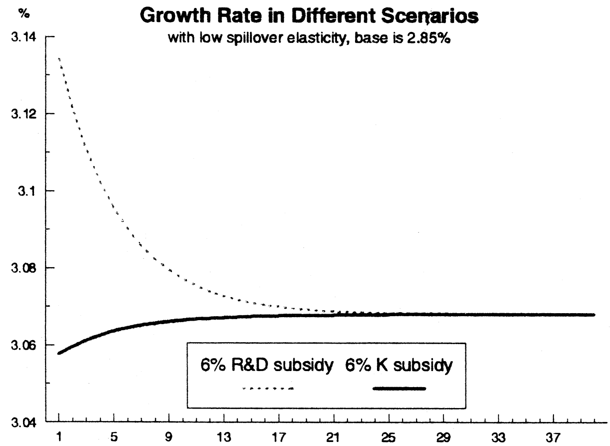

Fig. 5. Growth rate in different scenarios with low spillover elasticity; base is 2.85%.

the first year's adjustment, the rate of growth of inputs demanded by the R&D diminishes along the transition path.

When the R&D production cost is reduced by the subsidy, the stream of monopoly rents from the acquirement of the property rights to new blueprints rises. This stream of rents provides incentives to incur the fixed cost of acquiring a new blueprint, i.e., to increase the rate of creating new monopoly firms to enter the capital production sector.

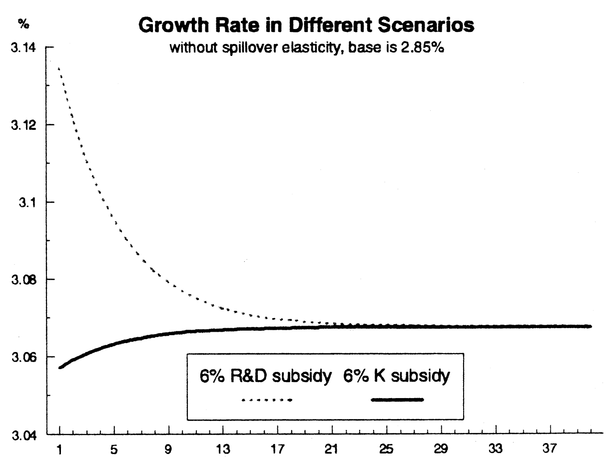

Fig. 6. Growth rate in different scenarios without spillover elasticity; base is 2.85%.

Changes in the prices and quantities of final goods along their transition paths differ from those in the steady-state, and especially so in the initial year. While the increase in the employment of the primary inputs in R&D increases R&D output instantaneously, time is required for differentiated capital to accumulate to ''compensate'' for the final goods sectors' loss of the primary resources which are re-allocated away and to R&D production. Consequently, the outputs of all final goods fall in the first few years following the implementation of the R&D subsidy. In the long-run, increases in the R&D output enlarges the pool of domestic technical knowledge. Such spillovers of ''domestic'' knowledge increase the productivity of the primary factors employed in the R&D activity. Thus, the output of blueprints rises steadily along both the transition and the steady-state paths. Concomitant with the increase in the production of blueprints is the increase in capital varieties. Employment of the increased number of differentiated capital in the final good production in turn increases the productivity of the primary resources in a Hick's neutral manner. Thus, compared with the base-run, outputs for all sectors start to increase after certain years, and the positive output gap rises as more years are taken into account.

As noted by the econometric analyses cited earlier, more own R&D stock is likely to allow a country to acquire relatively larger spillovers from the technological advances in the rest of world. Our simulation results, as well, show that subsidizing domestic R&D activity stimulates cross-border R&D spillovers by increasing the share of investment good imports along the transition. However, their long-run effects are quite modest. The reason is that when more resources are absorbed by the domestic R&D activity, the production of final outputs falls initially following the implementation of the R&D subsidy, and the increases in investment demand have to be met by increases in imports. Over time, as the number of capital varieties expands, the domestic production of the investment goods rises and import demand declines. Consequently, the evolution of the cross-border spillovers are not uniform over time, and their effects on the long-run growth rate are marginal (Table 2, comparing column 1 with 2 in row 8).

We observe significant welfare gains with the R&D subsidization policy. Interestingly, however, in the initial 5 years there is a welfare loss. This is due to the consumption forgone to increase investment. Over time, as productivity rises due to enlarged domestic pool of R&D knowledge and the accumulation of capital varieties, consumers begin to enjoy the gains from faster growth at the 6th year. The equivalent variation index of the first 10, 20, 30, and 50 years indicate a 0.8, 2.9, 5 and 9.6% welfare gain, respectively, and an almost 40% gain over the entire full path, including the gains in the steady-state (Table 2).

4.2.2. Adjustments induced by subsidizing differentiated capital used in final production

Subsidizing the rental price of differentiated capital paid by the final producers results, initially, in a re-allocation of primary resources at levels comparable to those when R&D activity is subsidized. However, in this environment, the mechanism causing this re-allocation is different. In the case of the direct R&D subsidy, firms involved in R&D activity bid primary resources away from the other sectors. In the case of subsidizing the employers of differentiated capital, on the other hand, the direct beneficiaries are the final good producers. The subsidy to the rental price of differentiated capital inputs induces them to increase factor demand. The subsidy results in a higher price received by the monopoly firms who own capital varieties but a lower cost for the final producers. The rise in the monopoly price induces the monopoly firms to develop new blueprints and produce more capital varieties.

Thus, while the two policies differ in their respective mechanisms for stimulating growth, they nevertheless generate similar results, i.e., the R&D activities compete for more resources to increase output, which in turn increases domestic technological spillovers and a higher rate of economic growth. Furthermore, the welfare gains are comparable in both cases (see Table 2).

5. Conclusions

In this paper, we introduce and explore an applied R&D-driven endogenous growth model, whose analytical antecedents are the models of Romer (1990) and Grossman and Helpman (1991). Utilizing evidence from recent econometric studies on sources of growth, the model also takes into account explicitly the mechanism whereby cross-border technological spillovers augment the stock of domestic technical knowledge. The model depicts a multi-sector open economy whose major trading partners are explicitly identified. It is calibrated to ''real'' economy data, Japan, and is solved to obtain both the transitional and steady-state equilibria. We explore the effects of selective trade and R&D promotion policies on the accumulation of domestic technological knowledge and the exploitation of the cross-border spillovers.

The results suggest that while trade policy has little effect on re-allocating resources into domestic R&D activities, it can significantly affect the cross-border spillovers of technological knowledge, which, in turn, increases the productivity of domestic resources employed in R&D activity. The social welfare implications are evaluated in terms of the equivalent variation index. We find that under a trade liberalization strategy wherein all tariff protection is eliminated in all sectors of the economy, welfare improves initially, but then declines continually, indicating a subsequent loss of social welfare in the long-run. In the dynamic framework with endogenously determined technological progress, welfare consequences of a policy are mainly driven by the long-run growth effects, and a *non-neutral* trade promotion policy providing selective market incentives to trade in investment goods (manufacturing industries) is bound to generate a more conducive environment for growth. These results suggest that trade policy designed to affect a country's long-run growth path should be targeted towards better utilization of foreign R&D capital stock by generating larger cross-border spillovers of technological knowledge. As R&D knowledge spillovers are carried by the investment good imports, a policy which is biased towards more open trade in investment goods could lead to a superior growth performance.

We next study the nexus of domestic R&D promotion policies under two cases: subsidizing the costs of R&D activities directly, and subsidizing the rental price of capital variety paid by the producers of final goods. Both of these policies generate less distortion in the economy but lead to more resources allocated to the domestic R&D activities which, in turn, raise the cumulative domestic R&D stock, and hence, the productivity of resources employed by the R&D. These policies not only encourage domestic R&D activity, they also allow the country to take greater advantage of foreign R&D by inducing investment good imports. Finally, we argue that direct subsidization on R&D may serve as a viable complement to selective trade promotion policies, as relying solely on strategic trade protection as instruments of long-run growth may prove unrealistically high tariff rates, especially in the post-Uruguay Round of a globalized world economy. We further found that the fiscal cost of R&D subsidies which succeed in attaining comparable rates of growth in return to strategic trade policies is relatively small, amounting to less than 1% of the GDP.

There is now a substantial amount of empirical and anecdotal evidence that Japan's targeting policy to affect sector- and firm-specific incentives has played a critical part in helping the country to attain high and sustained rates of growth; the same has been suggested for the other so-called high performing economies of East Asia (HPEAs). [12] This literature suggests that, starting from as early as the *Meiji* Japan (1862–1912), the East Asian model of economic development was based on maintaining close ties between the private enterprises and the government (Morishima, 1982). Policy makers deliberately chose, as a short cut for rapid development, to target *selective* industries and firms, rather than *all* sectors (Westphal, 1982, 1990; Amsden, 1989; Ohkawa and Kohama, 1989; Kwon, 1994). Furthermore, the private sectors benefited from a well-guided and active technology development policy (Wade, 1990; Lall, 1992, 1994).

However, it has to be noted that any policy should be pursued prudently to assure that the dead weight losses are outweighed by gains accruing from growth. As Bardhan (1990; p. 4) noted, ''As a matter of fact, almost all states in developing countries, successful or otherwise, are interventionist, and the important question is not really about the extent but the *quality* of that intervention'' (italic original). In this context, the policy insights of our modeling effort are

[12] See [6] above for the key references. See also the controversial papers by Amsden (1994), Kwon (1994), Lall (1994), Page (1994), in the Symposium on ''The World Bank Report: The East Asian Miracle'' in *World Development*, 22 (4), 1994.

suggestive of the routes for achieving a more conducive environment for sustained growth and improved welfare.

6. Glossary

Parameters

A_i	shift parameter in value added function
Γ_i	shift parameter in CET function
Λ_i	shift parameter in Armington function
A_k	shift parameter in differentiated capital production function
α_{Fi}	share parameter for factor F in value added function
α_k	share parameter for differentiated capital in value added function
a_{ij}	input–output coefficient for i used in j
μ_i	share parameter in CET function for foreign good
υ_i	share parameter in Armington function for foreign good
θ_F	share parameter for factor F in R&D production function
η_i	share parameter in differentiated capital production function for good i
γ_i	share parameter in household demand function for i
ξ	spillover elasticity in domestic R&D production function
$\varepsilon_{\mathrm{m}i}$	elasticity of substitution in Armington function
$\varepsilon_{\mathrm{e}i}$	elasticity of substitution in CET function
ρ	rate of consumer time preference
σ	inverse elasticity of intertemporal substitution in consumption

Exogenous variables (the time subscriptions are omitted)

L	labor supply
G	scientist/engineer supply
B	non-human resource supply
FRD_r	R&D stock of region r
mt_i	tariff rate for i
ht	income tax rate for household
PWM_i	world import price for good i
PWE_i	world export price for good i

Endogenous variables (the time subscriptions are omitted)

PC	price index for household over all consumption
PX_i	producer price for good i
PD_i	price for good i produced and consumed domestically
PE_i	price for good i exported
P_i	price for composite good i
PVA_i	value added price for good i
$P_{\mathrm{R\&D}}$	price for blueprints
MC_k	marginal cost for the production of differentiated capital

W_F	rental rate of factor F
P_k	monopoly capital rental price
X_i	output of good i
CC_i	total absorption of composite good i
DX_i	good i produced and consumed domestically
$M_{i,r}$	good i imported from region r
$\mathrm{MID}_{i,r}$	investment good i imported from region r
EX_i	good i exported
TC	household overall consumption
C_i	household demand for composite good i
ID_i	investment demand for composite good i
ITD_i	intermediate demand for composite good i
Y	household income
SAV	household savings
ω	share of imported capital goods in total investment demand
k	a single capital variety
π	monopoly profit for one firm
ΔHRD	new domestic blueprints
HRD	the accumulated R&D outputs
r	interest rate
g	growth rate

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Appendix A. The mathematical presentation of the model

(For all within period equations, time subscript, t, is skipped.)

A.1. The final output sectors

$$X_i = \min\left\langle A_i L_i^{\alpha_{L_i}} G_i^{\alpha_{G_i}} B_i^{\alpha_{B_i}} \mathrm{HRD} k^{\alpha_k}, a_{ji} \mathrm{ITD}_{ji_{j=1,2,\dots,7}} \right\rangle \tag{A1}$$

$$\alpha_{L_i} + \alpha_{G_i} + \alpha_{B_i} + \alpha_k = 1$$

A.2. The R&D sector

$$\Delta \mathrm{HRD} = A_{\mathrm{R\&D}} L_{\mathrm{R\&D}}^{\theta_L} G_{\mathrm{R\&D}}^{\theta_G} B_{\mathrm{R\&D}}^{\theta_B} \mathrm{HRD}, \quad \sum_F \theta_F = 1 \tag{A2}$$

$$A_{\mathrm{R\&D}} = \left(1 + \xi \sum_r \omega_r \mathrm{FRD}_r\right) \bar{A}_{\mathrm{R\&D}} \tag{A3}$$

$$\omega_r = \frac{\sum_i \mathrm{PWM}_i \mathrm{MID}_i}{\sum_i \mathrm{PC}_i \mathrm{ID}_i}, \quad i \in \mathrm{MFC} = \langle \mathrm{tnm,ome,omf} \rangle. \tag{A4}$$

A.3. The differentiated capital and investment decision

$$(\Delta \mathrm{HRD}k + \mathrm{HRD}\Delta k) = A_k \prod_{i=1}^{7} \mathrm{ID}_i^{\eta_i} \tag{A5}$$

$$\mathrm{MC}_k(\Delta \mathrm{HRD}k + \Delta k \mathrm{HRD}) = \sum_{i=1} P_i \mathrm{ID}_i \tag{A6}$$

$$P_k = \frac{r \mathrm{MC}_k}{\alpha_k} \tag{A7}$$

$$\pi = (1 - \alpha_k) P_k k \tag{A8}$$

$$(1 + r_t) P_{\mathrm{R\&D}_{t-1}} = \pi_t + P_{\mathrm{R\&D}_t} \tag{A9}$$

A.4. The intertemporal utility, budget constraint, consumption and saving decision

$$\sum_{t=1}^{\infty} (1+\rho)^{-t} \frac{\mathrm{TC}_t^{1-\sigma} - 1}{1 - \sigma} \tag{A10}$$

$$\mathrm{TC} = \prod_{i=1}^{7} C_i^{\gamma_i}, \quad 0 < \gamma_i < 1, \quad \sum_i \gamma = 1 \tag{A11}$$

$$Y = W_L L + W_G G + W_B B + P_k \mathrm{HRD}k + \mathrm{TR} \tag{A12}$$

$$\mathrm{SAV} = (1 - \mathrm{ht}) Y - \mathrm{PTC} \cdot \mathrm{TC} \tag{A13}$$

$$\frac{1+\rho}{1+r_{t+1}} \left(\frac{\mathrm{TC}_{t+1}}{\mathrm{TC}_t} \right)^{\sigma} = \frac{\mathrm{PTC}_t}{\mathrm{PTC}_{t+1}} \tag{A14}$$

$$\mathrm{PTC}_t \mathrm{TC}_t = \sum_{i=1}^{7} \mathrm{PC}_{i_t} \mathrm{C}_{i_t} \tag{A15}$$

A.5. The CET functions and export supply

$$X_i = \Gamma_i\left(\mu_i \mathrm{EX}_i^{(1+\varepsilon_{\mathrm{e}i})/\varepsilon_{\mathrm{e}i}} + (1-\mu_i)\mathrm{DX}_i^{(1+\varepsilon_{\mathrm{e}i})/\varepsilon_{\mathrm{e}i}}\right)^{\varepsilon_{\mathrm{e}i}/(1+\varepsilon_{\mathrm{e}i})} \tag{A16}$$

$$\mathrm{EX}_i = (\mu_i \mathrm{PX}_i/\mathrm{PE}_i)^{-\varepsilon_{\mathrm{e}i}} \Gamma_i^{-(\varepsilon_{\mathrm{e}i}+1)} X_i \tag{A17}$$

$$\mathrm{PX}_i X_i = \mathrm{PD}_i \mathrm{DX}_i + \mathrm{PE}_i \mathrm{EX}_i \tag{A18}$$

A.6. The Armingtonian functions and import demand

$$\mathrm{CC}_i = \Lambda_i\left(\sum_r^3 \nu_{r_i} M_{r_i}^{(\varepsilon_{\mathrm{m}i}-1)/\varepsilon_{\mathrm{m}i}} + \left(1-\sum_r^3 \nu_{r_i}\right)\mathrm{DX}_i^{(\varepsilon_{\mathrm{m}i}-1)/\varepsilon_{\mathrm{m}i}}\right)^{\varepsilon_{\mathrm{m}i}/(\varepsilon_{\mathrm{m}i}-1)} \tag{A19}$$

$$M_{r_i} = \left(\frac{\nu_{r_i}\mathrm{PC}_i}{(1+\mathrm{tm}_{r_i})\mathrm{PWM}_i}\right)^{\varepsilon_{\mathrm{m}i}} \Lambda^{\varepsilon_{\mathrm{m}i}+1}\mathrm{CC}_i \tag{A20}$$

$$\mathrm{PC}_i \mathrm{CC}_i = \mathrm{PD}_i \mathrm{DX}_i + \sum_{\mathrm{r}}^3 (1+\mathrm{tm}_{\mathrm{r}_i})\mathrm{PWM}_i M_{\mathrm{r}_i} \tag{A21}$$

A.7. Factor market equilibrium

$$\sum_i^7 \alpha_{F_i} \mathrm{PVA}_i X_i + \theta_F P_{\mathrm{R\&D}} \Delta \mathrm{HRD} = W_F F, \quad F = L, G, B; \tag{A22}$$

$$\sum_i \alpha_k \mathrm{PVA}_i X_i = P_k \mathrm{HRD}k \tag{A23}$$

A.8. Demand system

$$P_i C_i = \gamma_i \mathrm{PCTC} \tag{A24}$$

$$\mathrm{ITD}_i = \sum_j^7 a_{ij} X_j \tag{A25}$$

$$P_i \mathrm{ID}_i = \eta_i \mathrm{MC}_k (\Delta \mathrm{HRD}k + \mathrm{HRD}\Delta k) \tag{A26}$$

A.9. Commodity market equilibrium

$$\mathrm{CC}_i = C_i + \mathrm{ID}_i + \mathrm{ITD}_i \tag{A27}$$

A.10. Balanced payment condition

$$\sum_{i=1}^{7}\left(\mathrm{PWM}_i \sum_{r}^{3} M_{r_i} - \mathrm{PWE}_i \mathrm{EX}_i\right) = 0 \tag{A28}$$

$$\mathrm{SAV} = \sum_{i=1}^{7} \mathrm{PC}_i \mathrm{ID}_i + P_{\mathrm{R\&D}} \Delta \mathrm{HRD} \tag{A29}$$

A.11. Knowledge accumulation

$$\mathrm{HRD}_{t+1} = \Delta \mathrm{HRD}_t + \mathrm{HRD}_t \tag{A30}$$

A.12. Growth rate

$$g_t = \frac{\Delta \mathrm{HRD}_t}{\mathrm{HRD}_t} \tag{A31}$$

A.13. Steady-state constraints

$$\left(\frac{1 + r_{\mathrm{ss}}}{1 + \rho}\right)^{1/\sigma} = 1 + g_{\mathrm{ss}} \tag{A32}$$

$$r_{\mathrm{ss}} = \frac{\pi_{\mathrm{ss}}}{P_{\mathrm{R\&D}_{\mathrm{ss}}}} \tag{A33}$$

A.14. Index of equivalent variation

$$\sum_{t=1}^{T} (1+\rho)^{-1} \frac{\left[\hat{\mathrm{TC}}_t (1+\phi)\right]^{1-\sigma} - 1}{1-\sigma} = \sum_{t=1}^{T} (1+\rho)^{-1} \frac{\mathrm{TC}_t^{1-\sigma} - 1}{1-\sigma} \tag{A34}$$

where $\mathrm{T\hat{C}}_t$ is total consumption in ''base-run''. That is, welfare gain resulting from the policy change is equivalent from the perspective of the representative household to increasing the reference consumption profile by ϕ%.

A.15. Equations for calibration

For clarity, we use bar to indicate parameters or benchmark values for some variables which are specified exogenously and hat to indicate benchmark variables which are given by the data from the Social Accounting Matrix. Symbols without a bar or a hat are the values calibrated for the benchmark.

Define

$$\mathrm{G\hat{D}P} \equiv \sum_i \mathrm{PVA}_i X_i + P_{\mathrm{R\&D}} \Delta \mathrm{HRD} = \overline{W}_L \hat{L} + \overline{W}_G G + \overline{W}_B B + \overline{P}_k k \mathrm{H\overline{R}D} \tag{A35}$$

where $W_L = W_B = P_k = 1$, $W_G = 2W_L$, $W_B B + P_k \mathrm{HRD} k$ are the returns to the total capital in the data, but not $W_B B$ and $P_k \mathrm{HRD} k$ individually. Hence, $\mathrm{G\hat{D}P}$ can be obtained from the data, and PVA_i are calculated from:

$$\mathrm{PVA}_i = \mathrm{P\overline{X}}_i - \sum_j \hat{a}_{ji} \mathrm{P\overline{C}}_j \tag{A36}$$

and $\mathrm{PX}_i = \mathrm{PC}_i = 1$.

Choosing the data about the share of R&D expenditure in GDP obtains the value of $P_{\mathrm{R\&D}} \Delta \mathrm{HRD}$. $\Delta \mathrm{HRD} = g \mathrm{HRD}$ from Eq. (A32). Then, we get $P_{\mathrm{R\&D}}$.

Combining Eqs. (A7), (A8) and (A33), with Eq. (A37) below:

$$\mathrm{SAV} = \mathrm{MC}_k \Delta \mathrm{HRD} k + P_{\mathrm{R\&D}} \Delta \mathrm{HRD} \tag{A37}$$

we obtain

$$\mathrm{SAV}(1 - \alpha_k) = P_{\mathrm{R\&D}} \Delta \mathrm{HR\hat{D}} \tag{A38}$$

Combining Eqs. (A24) and (A25) and using Eq. (A8) again we obtain:

$$\alpha_k (1 - \alpha_k) \left(\mathrm{GD\hat{P}} - P_{\mathrm{R\&D}} \Delta \mathrm{HR\hat{D}} \right) = \bar{r} P_{\mathrm{R\&D}} \mathrm{HR\hat{D}} \tag{A39}$$

Eqs. (A38) and (A39) are used to solve for SAV and α_{k}.

Once we have α_k, MC_k is obtained from Eq. (A7). Thus, we obtain k from Eq. (A37), i.e.,

$$k = \frac{\mathrm{SAV} - P_{\mathrm{R\&D}} \Delta \mathrm{HRD}}{\mathrm{MC}_k \Delta \mathrm{HRD}} \tag{A40}$$

Then, B is obtained by subtracting $\overline{W}_L \hat{L} + \overline{W}_G \hat{G} + \overline{P}_k \mathrm{H\overline{R}D} k$ from $\mathrm{G\hat{D}P}$.

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