Innovation, Trade and Finance*

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Abstract

The paper proposes a model where heterogeneous firms choose whether to undertake R&D or not. Depending on R&D choice, innovative firms are more productive, have larger investment opportunities and lower own funds than non-innovating firms. As a result, innovative firms are financially constrained while standard firms are not. The efficiency of the financial sector and a country's institutional quality relating to corporate governance determine the share of R&D intensive firms and the comparative advantage in innovative goods. We show how protection, R&D subsidies and financial development improve access to external finance in distinct ways, support the expansion of innovative industries and boost national welfare. International welfare spillovers depend on the interaction between terms of trade effects and financial frictions and may be positive or negative, depending on foreign countries' trade position.

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1 Introduction

Innovative firms are more frequently finance constrained than less innovative ones. Being innovative, they tend to have large investment opportunities but may not be able to fully exploit them because of credit rationing. R&D intensive sectors are thus financially dependent in the sense of Rajan and Zingales (1998). Access to finance and the quality of the financial system becomes important for the expansion of innovative industries. In this paper, building on earlier work by Keuschnigg and Ribi (2010) and Egger and Keuschnigg (2010), we propose a two sector model that endogenously explains the emergence of finance constraints. We distinguish between a standard sector where the Modigliani Miller irrelevance theorem applies, and an innovative sector where firms are potentially constrained in the access to external finance. Innovative sector production is driven by entrepreneurial firms which are heterogeneous in their early stage survival probabilities. After entry, they decide whether or not to undertake a discrete R&D investment with two consequences: (i) R&D spending uses up own assets and (ii) creates higher productivity which results in a larger optimal scale of expansion investment. These firms are the prototype of highly productive growth companies with few own assets and large investment opportunities, are financially dependent and require a large amount of external funds. Non-innovative, standard firms do not invest in R&D and are left with undiminished and relatively large own assets but low productivity. Being less productive, these firms optimally invest at a small scale and are naturally unconstrained.

Since the fraction of innovative growth companies in the R&D intensive sector results from a discrete innovation decision, our model endogenously explains not only the constrained level of investment per firm and the resulting excess return on capital, but also the share of firms subject to finance constraints. In other words, we explain the role of finance constraints in determining the intensive and extensive margins of innovative firm investments. Finance constraints result from a moral hazard problem in the relationship between an entrepreneur and outside investors as in Holmstrom and Tirole (1997) and Tirole (2001, 2006). For external funding to be incentive compatible, entrepreneurs must keep a minimum stake in the firm which limits the amount of funds (pledgeable income) that are available to pay back external credit. The amount of pledgeable income thus determines the firm's debt capacity, the amount of external funds that it can raise from banks or other outside investors.

We explicitely model the quality of financial intermediation by introducing the monitoring capacity of a country's banking sector. Specifically, we distinguish between passive, standard banks and active intermediaries supplying monitoring services. Active intermediaries might be venture capitalists, specialized investment banks, 'Hausbanken' or other intermediaries engaged in relationship banking. On the negative side, monitoring is costly and raises the cost of capital. On the positive side, monitoring narrows down private benefits from managerial misbehavior, relaxes the incentive constraint and raises firms' debt capacity. Improving access to external credit boosts firm value since it allows to undertake additional investments with an above normal return. If monitoring is sufficiently productive, monitoring capital becomes valuable to innovative firms even if it is more expensive than standard bank financing. In our model, innovative firms thus have multiple sources of external funds. They attract a minimum amount of expensive monitoring capital while the remaining credit comes from standard bank financing.

Having introduced a monitoring role of the banking sector, we interpret financial sector development to mean that active banks become more productive in performing monitoring functions at a given marginal cost. Since more intensive monitoring boosts access to external funds, a country with a more developed financial sector should have more innovative firms, because monitoring is useful only to constrained firms, and these firms should invest at a larger scale, compared to countries with a less mature financial sector. Financial sector development thus relaxes finance constraints on the intensive and extensive margins and thereby encourages innovation by R&D intensive growth companies. The financial sector becomes a source of comparative advantage in innovative industries.

Based on this framework, the paper investigates the role of three alternative policy approaches which address financial frictions in distinct ways. The key results are the following. Assuming that the home country is importing innovative goods, we find that import protection, in raising the domestic price and earnings per firm, also boosts the debt capacity of constrained firms. Protection thereby relaxes finance constraints and allows innovative firms with an above normal rate of return to invest at a larger scale. For this reason, a small level of protection can raise domestic welfare, provided that terms of trade effects in the importing country are small. The second policy is an R&D subsidy which boosts innovation and welfare, not because of knowledge spillovers which are excluded in our model, but because these subsidies strengthen the internal funds for financing subsequent expansion investment. Being left with larger own assets after R&D spending, innovating firms succeed to attract a larger amount of external funds, allowing them to more fully exploit profitable investment opportunities with an excess rate of return. The policy again boosts national welfare and shifts comparative advantage towards the innovative sector.

Finally, we investigate the consequences of financial sector development. A higher monitoring productivity also raises firms' debt capacity, relaxes finance constraints in the innovative sector and boosts national welfare. The quality of the financial sector becomes a source of comparative advantage in the R&D intensive and financially dependent sector. While all three policies reduce financial frictions in the innovative sector and yield welfare gains at home, the consequences on foreign welfare are less clear and depend on the specific interaction of terms of trade effects and financial frictions. The reduction in the world price strongly hurts foreign export nations, not only because of a negative terms of trade effect, but also because the lower prices tightens finance constraints. In foreign import countries, the lower price yields positive terms of trade effects which tend to offset the negative consequences on financial frictions.

The unique and novel contributions of the present paper are the following. First, we endogenously explain the emergence of financing constraints by a discrete innovation decision which splits firms into highly productive, constrained firms with large investment opportunities and less productive unconstrained firms optimally investing at a small scale. The share of innovative and financially dependent firms and their constrained level of equipment investment is endogenously explained. Average productivity and R&D intensity in the innovative sector is thus determined by the degree of financial frictions. Second, we investigate and compare how three different policy approaches, consisting of protection, R&D subsidies and financial development, affect financial constraints, national equilibrium and the trade pattern of a country. Instead of analyzing institutional country characteristics such as corporate governance, accounting standards and investor protection etc. (as in Egger and Keuschnigg, 2010, for example), we analyze here the differences in financial sector efficiency accross countries relating to the monitoring functions of financial intermediaries. Third, we provide a complete analysis of national and international welfare consequences of these policy alternatives and show how they depend on the interaction between terms of trade effects and financial frictions.

The paper proceeds as follows. The next section provides a literature review. Section 3 sets up the model, Section 4 analyzes equilibrium and comparative static effects of policy intervention in a small open economy, and Section 5 turns to policy effecs in a large economy in world equilibrium. The concluding section summarizes the key insights.

2 A Review of the Literature

The main building blocks of our model are well backed by empirical evidence. The theoretical prediction of the cash-flow sensitivity of investment has been studied extensively in the empirical literature (for a survey, see Hubbard, 1998). Schaller (1993) and Chirinko and Schaller (1995) find correlations between physical capital investment and internal funds around 0.4 for small firms, which are substantially higher than the corresponding values of around 0.2 for large firms. Apart from firm size, another criterion that differentiates constrained and unconstrained firms, is their banking relationship. When firms have close ties to banks, the informational asymmetry is reduced, and they are more likely to obtain the required funding for their projects. Hoshi, Kashyap, and Scharfstein (1991) indeed report investment - cash flow sensitivities of only around 0.05 for these types of firms in Japan, whereas correlations for independent firms vary between 0.45-0.5. Similar numbers are found by Schaller (1993) and Chirinko and Schaller (1995) who separate firms according to their relationship to other groups of firms. Spending on physical assets captures only part of a firm's total investments. When all categories including working capital are taken into account, the sensitivity of total investment to cash flow in constrained firms typically exceeds 1 (Fazzari and Petersen, 1993; Calomiris and Hubbard, 1995; Carpenter and Petersen, 2002). Kaplan and Zingales (1997) emphasize that investments of constrained firms should be sensitive to internal cash-flow while investment of unconstrained firms should not. However, the magnitude of the sensitivity does not necessarily increase in the degree of financing constraints.

Rajan and Zingales (1998) show that financing constraints are prevalent in countries with poorly developed financial markets and that these restrictions impair the growth of companies dependent on external finance. In differentiating by firm size, Beck, Demirgüc-Kunt, and Maksimovic (2005) find that financing constraints are most relevant for small firms. As financial and institutional characteristics improve, constraints become less tight. Small firms catch up and benefit the most. These results are confirmed by Beck, Demirgüc-Kunt, and Maksimovic (2008) who focus on the importance of alternative sources of finance for small and large firms. Well developed property rights boost external financing in small firms more strongly than in large firms. The increase mainly results from easier access to bank credit. Other sources of finance are not able to compensate for lacking access to bank financing. The same finding is reported by Fisman and Love (2003) who study trade credit as an alternative funding source when financial markets are poorly developed. The importance of firm size for financial market access is already apparent when a firm is created (see Aghion, Fally, and Scarpetta, 2007). Financial development most strongly raises entry rates of smaller firms whereas entry of larger firms shows no or even a negative response. Even in advanced economies, there is scope to promote entry of small firms and their subsequent growth by improving institutions.

Innovative firms are more likely to become credit rationed. Because of its novelty and potentially high technical sophistication, an innovative business idea aggravates information problems for outside investors. Further, the knowledge to carry out the project successfully is often intrinsic which makes the entrepreneur's effort essential but, at the same time, also very difficult to monitor. In addition, since innovative firms by their very definition are highly productive, they have large investment opportunities and need large external funds which, again, makes it likely that the financing capacity is exhausted and investment becomes finance constrained. The empirical literature confirms that external financing of R&D activities itself, especially in small firms, is severely constrained and must, to a very large extent, be self-financed (Himmelberg and Petersen, 1994; Ughetto, 2008; Hall, 2002; Hall and Lerner, 2009). The cost of capital that is used for R&D spending is much higher than the one associated with more traditional investment. In our model, we have assumed R&D spending to be fully self-financed. Furthermore, Guiso (1998) and Ughetto (2009) show that innovative firms are in general more likely to be constrained in all their activities requiring external funding which makes them unable to fully exploit the investment potential created by their innovations.

The empirical literature has extensively studied the effects of innovation incentives and tax credits on private R&D. With regard to fiscal R&D incentives, Hall and Van Reenen (2000) conclude that one dollar in tax credits leads to about one dollar of additional business R&D. In their cross-country study, Bloom, Griffith and Van Reenen (2002) find that when tax credits reduce the cost of R&D by 10%, one can expect the level of R&D activity to rise by roughly 10% in the long run. More so than with standard investment, the quality of inventions, their market potential and innovative firms' investment opportunities are difficult to judge by outside investors. The empirical literature confirms that capital costs are higher for R&D intensive investment than for standard investment, especially for small firms (cf. Hall, 2002; Hall and Lerner, 2009). Consistent with the fact that these firms mainly rely on internal resources to finance their innovation activities, the correlation between investment and own cash flow is also significantly higher for the R&D intensive investment category (Brown and Petersen, 2009).

In international economics, early theoretical work by Kletzer and Bardhan (1987) and Baldwin (1989) delivered key hypotheses about the tightness of credit constraints (through differences between countries' domestic institutions for credit enforcement) as a source of comparative advantage in the production of goods which require more credit than other goods. Evidence in favor of that view has been provided by Beck (2002, 2003), Svaleryd and Vlachos (2005), and Manova (2008a). This research concludes that countries with better developed financial institutions have a comparative advantage in industries which rely more intensively on external finance, and financial market liberalization increases exports disproportionately more in financially vulnerable sectors where firms require more outside finance and have fewer assets serving as collateral. The results in Svaleryd and Vlachos (2005) indicate that differences in financial systems may be even more important for specialization patterns than differences in human capital.[1] Gorodnichenko and Schnitzer (2010) examine how financial constraints affect a firm's innovation and export activities. In testing their theoretical predictions, they find unambiguous evidence that financial constraints strongly impair the ability of firms to innovate and to export.

Part of the work on finance constraints in open economies focuses on trade and international capital flows. For instance, Matsuyama (2004) explores how financing frictions determine capital flows in a one-good world economy. Matsuyama (2005) studies trade and capital flows in a Ricardian model with a continuum of goods where hiring of workers is constrained by a firm's pledgeable income to pay wages. The 'borrowing constraint' thus relates to hiring rather than investment. Antras and Caballero (2009) develop a $2 \times 2 \times 2$ model where one sector is financially constrained and the other is not. A key result is that trade and capital movements are complements in financially less developed countries. Ju and Wei (2008) develop a $2 \times 2 \times 2$ trade model with mobile capital where sectors differ by the extent of financial frictions and firms within sectors are homogeneous. They emphasize that, in addition to factor endowments and technology, the quality of institu-

[1] Do and Levchenko (2007) present evidence that financial development depends on trade patterns and argue that financial development is endogenous and in part determined by the demand for external financing which might be influenced by trade patterns shifting towards financially dependent sectors.

tions determines the patterns of trade and capital flows. This literature mainly embeds financial constraints in models with otherwise classical or neoclassical – Heckscher-Ohlin or Ricardian – reasons for trade.

Some recent theoretical work abstracts from classical endowment- and productivity-related motives for trade and focuses on the role of financial constraints on the entry of heterogeneous firms in new trade models. For instance, Manova (2008b) embeds financial constraints in a one-sector model of heterogeneous firms and illustrates how finance constraints not only affect the pattern but even the volume of trade through firm selection. A novel insight is that productivity of firms in a market is endogenously determined by financial constraints and their impact on firm selection. Chor, Foley, and Manova (2008) introduce credit constraints in the model of export-platform FDI of Helpman, Melitz, and Yeaple (2004) with heterogeneous firms. In particular, they model credit constraints to arise from the imperfect protection of lenders against default risk. Host country financial development leads to more competition for subsidiaries of foreign-owned firms in that market. The latter leads to a larger fraction of foreign affiliate exports to third countries relative to their total sales and, hence, a more extensive use of these subsidiaries as export platforms. They find evidence in support of this hypothesis in a panel data-set of U.S. foreign affiliates for the years 1989-1998. In a model with financial frictions, Antras, Desai and Foley (2009) argue that weak investor protection limits the scale of multinational firm activity, increase the reliance on foreign direct investment flows, and alters the decision to deploy technology through FDI as opposed to arm's length technology transfers. They test and confirm these predictions with firm level-data.

3 The Model

3.1 Overview

We develop a multicountry model of innovation, trade and finance, including two goods and two factors in each country. We first introduce the structure of the domestic economy, taking the world prices as given. A standard sector produces the *numeraire* good with a Ricardian technology that transforms one unit of labor into one unit of output, and one unit of a capital good into R units of output. The attention mainly focusses on the innovative sector which consists of heterogeneous, entrepreneurial firms. These firms are driven by entrepreneurs who make risky innovation and investment choices. They have limited own assets and are potentially finance constrained.

Capital and labor endowments are distributed among risk-neutral agents. There are L workers without assets who have no managerial talent and can only work in the Ricardian sector, earning a competitive wage equal to unity. The country also hosts a mass 1 of wealthy individuals endowed with assets A per capita. A *fixed* fraction E has entrepreneurial ability, the others not. Part $1 - E$ can invest A either in deposits paying a safe interest r, or in a linear investment technology which transforms one unit of endowment into $R = 1 + r$ units of the standard good. The Ricardian technology in the standard sector fixes the deposit rate as well as the wage rate. Entrepreneurs run a firm in the innovative sector and earn an expected surplus π_E on top of AR. Hence, all E individuals who are able to manage a firm, prefer to invest all their wealth in their own firm, rather than investing in the capital market. A firm's life-cycle consists of three stages, an early R&D phase, an expansion phase with physical capital investment, and a mature production stage. Firms can fail both in the R&D and expansion stage. At the beginning, entrepreneurs draw a risky project of type $q' \in [0, 1]$ from the distribution $G(q) = \int_0^q g(q')\, dq'$. Types differ by the early stage success probability q' of the project. Conditional on surviving the early R&D stage, firms may still fail with probability $1 - p$ during the expansion stage where the success rate p is a matter of managerial effort.

Depending on occupational activity and on success and failure in entrepreneurship, a specific person i may have quite different income y_i. All agents are endowed with preferences that are linearly separable in consumption and private benefits B_i (leisure), $u_i = u(c_{iN,} c_{iE}) + B_i$, where u is linearly homogeneous and c_{iN} and c_{iE} refer to consumption of standard and entreprenerial, innovative goods. Financial contracts will prevent shirking so that private benefits of entrepreneurs are zero in equilibrium. Given end of period income y_i and a relative price v, demand follows from

$$u_i = \max_{c_{iN},c_{iE}} \{u(c_{iN},c_{iE}) \quad s.t. \quad c_{iN} + vc_{iE} \leqslant y_i\}. \tag{1}$$

Welfare is equal to real income, $u_i = y_i/v_D$, and changes by $\hat{u}_i = \hat{y}_i - \hat{v}_D$. The exact consumer price index $v_D(v)$ adjusts according to $\hat{v}_D = \eta\hat{v}$. Without loss of generality, we specialize to Cobb Douglas preferences, implying fixed expenditure shares, $\eta \equiv vc_{iE}/y_i$ and $1 - \eta \equiv c_{iN}/y_i$.

Workers are subject to a lump-sum tax T, giving income $y_L = 1 - T$ per capita. Investors earn $y_I = AR$ independent of asset allocation while entrepreneurs earn on average more than investors, $y_E = AR + \pi_E$. Expected profit π_E reflects a rent so that all E agents with entrepreneurial ability indeed prefer to invest in their own firm. However, when the business fails, all assets are lost and income drops to zero. Early on, firms may invest an amount k in R&D spending which yields a higher productivity. The government can grant a specific subsidy σ which reduces private R&D cost to $k - \sigma$. The returns to R&D accrue only if a firm survives the start-up period. Hence, only those firms with a high survival chance q' find it worthwhile to invest in R&D. Firms with a low survival chance are not able to sufficiently benefit from innovation and do not invest in R&D. Since the firm's project might be of any possible type q', expected profit is

$$\pi_E = \int_0^1 (\pi(q')q' - k(q')R)\,dG(q') = \int_0^q \pi_u q' dG(q') + \int_q^1 [\pi_c q' - k_c R]\,dG(q'). \tag{2}$$

The subindex points to innovative (type c, constrained) and standard firms (type u, unconstrained). When successfully completing the early stage, expected profit of an innovating firm is π_c while a standard one expects only π_u. As will be explained in more detail below, only firms with good projects $q' > q$ choose R&D, invest $k_c = k - \sigma$, and get larger profits $\pi_c > \pi_u$. Other firms do not innovate, avoid R&D spending ($k_u = 0$) and get a lower profit.

3.2 Innovation and Investment

Setting up an entrepreneurial firm with own assets A leads to the following sequence of events: (i) based on project type q', firms decide on R&D investment $k_j \in \{0, k - \sigma\}$, leaving residual assets $A_j = A - k_j$; (ii) when surviving the early stage, firms choose investment I_j and apply for credit $I_j - A_j$, possibly from different sources; (iii) when the investment is installed, entrepreneurs supply managerial effort and banks choose monitoring effort (if necessary), leading to a high success probability p if both types of effort are high. If financing is not incentive compatible, the success probability falls to $p_L < p$. Externally financed investment is subject to a double moral hazard where the incentive of an entrepreneur to supply high managerial effort depends on the monitoring level of the active bank, and vice versa; (vi) firms produce output and pay back external funds if investment is successful. In case of failure, either in the early innovation or the subsequent expansion stage, all assets are lost and the firm is closed down.

R&D investment in stage ii is assumed to be fully self-financed with own assets and, thus, reduces a company's internal resources available for self-financing of expansion investment. After self-financed R&D, firms have productivity θ_j and residual assets $A_j = A - k_j$. The R&D choice naturally dichotomizes innovative sector firms into cash-poor growth companies and cash-rich, but less productive standard firms. Innovative growth companies are highly productive, $\theta_c > 1$, but prior R&D leaves them with low assets $A_c = A - (k - \sigma)$. Non-innovating, passive firms are less productive but are left with relatively high assets, $\theta_u = 1$ and $A_u = A$. Given the assumptions below, and in line with observed firm characteristics, growth companies are finance constrained while standard firms are not. Being finance constrained, growth companies will not be able to fully exploit their investment opportunities. Furthermore, the fraction of finance constrained firms in the innovative sector will be endogenous, i.e. finance constraints operate on the extensive and intensive margins.

At the end of period, firms sell output $x_j = \theta_j f(I_j)$ in the innovative goods market at a relative price v while undepreciated capital I_j adds to traditional sector output. After innovation, the firm needs external funds $I_j - A_j$ to finance expansion investment. If necessary, it can obtain funds D_j^m from active, monitoring banks (e.g. venture capital, investment banks, 'Hausbanken') and $D_j = I_j - A_j - D_j^m$ from other passive banks. All financial institutions are assumed competitive. Expected profit π_j^e, equal to the surplus over residual assets A_j, amounts to

$$\begin{aligned} \pi_j^e &= p\left[I_j + vx_j - (1+i)\,D_j - (1+i^m)\,D_j^m\right] - RA_j, \\ \pi_j^m &= p\,(1+i^m)\,D_j^m - RD_j^m - c^m I_j = 0, \\ \pi_j^b &= p\,(1+i)\,D_j - RD_j = 0, \\ \pi_j &= p\,(I_j + vx_j) - c^m I_j - RI_j. \end{aligned} \tag{3}$$

Active banks incur real monitoring costs equal to $c^m I_j$, measured in terms of labor or sector 2 output. With competitive intermediation, profits of financial firms are zero so that entrepreneurs appropriate the full surplus $\pi_j^e = \pi_j$. This surplus is, however, reduced by monitoring costs if active banks are involved. Competition fixes the interest rate $i > r$ on standard business loans and yields a convenient form of expected profit,

$$p\,(1+i) = R \quad \Rightarrow \quad \pi_j = p\,(vx_j - iI_j) - c^m I_j. \tag{4}$$

We analyze the case where innovative firms find it preferable to raise more expensive monitored funds and, at the same time, cheaper non-monitored credit. Monitoring capital is more expensive since, in addition to the same refinancing cost R per Euro of credit, active banks must also cover monitoring cost. Being more expensive, firms will resort to monitoring capital only to the extent that they need it, and prefer to finance with standard credit to the largest possible extent.

Stage iii, managerial effort and monitoring: Once the firm has determined investment and raised the necessary external funds, it may fail due to a lack of effort. There is a double moral hazard in (discrete) effort choice. Low managerial effort results in a low success probability $p_L < p$ where $\nabla \equiv p - p_L$. When shirking and providing low effort, the success probability and, thus, expected income is low but the entrepreneur enjoys private benefits bI_j if she is monitored, and BI_j if she is not, where $B > b$. Monitoring thus makes shirking less rewarding. After external financing is arranged, entrepreneurs and banks know their income share in the success state. The size of their profit share determines whether the reward is large enough to motivate high monitoring and managerial effort. If successful, the entrepreneur gets residual earnings $y_j^e \equiv I_j + vx_j - (1+i)\,D_j - y_j^m$, while the monitor gets $y_j^m \equiv (1+i^m)\,D_j^m$. Given that she is monitored, high effort is chosen if the incentive compatibility condition is fulfilled,

$$
\begin{aligned}
IC^e \quad &: \quad py_j^e \geq p_L y_j^e + bI_j \quad \Leftrightarrow \quad y_j^e \geq \beta I_j, \quad \beta \equiv \frac{b}{\nabla}, \\
IC^m \quad &: \quad py_j^m \geq p_L y_j^m + c^m I_j \quad \Leftrightarrow \quad y_j^m \geq \gamma I_j, \quad \gamma \equiv \frac{c^m}{\nabla}.
\end{aligned} \tag{5}
$$

The monitoring condition reflects the following trade-off. Suppose the managerial incentive constraint is tight when the bank monitors. In this case, the monitoring bank gets py_j^m. If she does not monitor, the entrepreneur enjoys larger private benefits and prefers shirking which reduces the success probability to p_L. Expected repayment falls to $p_L y_j^m$, but the bank can assign employees hired for monitoring to other tasks generating income $c^m I_j$, leading to expected earnings of the bank equal to $p_L y_j^m + c^m I_j$. The incentive to monitor consists of the rise in expected income from disciplining the entrepreneur. With double moral hazard, both constraints must be satisfied simultaneously. The role of monitoring is to limit managerial discretion so that entrepreneurs are incentivized with a smaller income stake, leaving a larger part of cash-flow for repayment of external funds. Monitoring thus raises a firm's pledgeable income and improves access to external funds.

Stage ii, investment and external funds: If a firm is financially unconstrained, it chooses passive bank financing. Monitoring capital would only be more expensive but can play no useful role since there is no need to improve access to external funds. The first best level of investment maximizes expected profit $\pi_u^e = \pi_u$ in (3) with $c^m = 0$. As in neoclassical theory, the firm invests until the marginal return on investment is equal to the user cost of capital,

$$
vf'(I_u) = i, \quad \pi_u = p\,(vx_u - iI_u)\,. \tag{6}
$$

Banks are willing to lend (without monitoring) if the entrepreneur's incentive constraint is slack at this first best investment level.

Assumption 1 *(i) At I_u determined by $vf'(I_u) = i$, we have $y_u^e(I_u) > I_u B/\nabla$.*
(ii) At I_c determined by $v\theta f'(I_c) = i$, we have $y_c^e(I_c) < I_c B/\nabla$.

Part (ii) means that innovative firms are constrained. These firms are highly productive ($\theta_c > 1$) and have large investment opportunities but little internal assets as a result of prior R&D spending, $A_c = A - k + \sigma < A_u$. These two characteristics make innovative firms finance constrained.

We show below that a constrained firm benefits from attracting monitoring capital even though it is more expensive than passive bank credit. Given the higher cost, the firm raises as little as possible to incentivize the monitoring activity and sets a minimum repayment $y_c^m = \gamma I_c$ such that IC^m just binds. Given this repayment, the firm can raise monitored funds D_c^m until the participation constraint binds,

$$y_c^m = \gamma I_c, \quad D_c^m = (py_c^m - c^m I_c)/R = (p\gamma - c^m) I_c/R. \tag{7}$$

Reserving a part $y_c^m = \gamma I_c$ of cash-flow for repayment to monitors reduces the entrepreneur's residual income. To guarantee managerial effort, the entrepreneur must keep a minimum income given by the incentive constraint $y_c^e \geq \beta I_c$ which is much lower with monitoring than without. Both incentive compatible income stakes limit the amount of repayment that can be pledged to passive banks. Hence, the firm's residual debt capacity is restricted by $(1+i) D_c \leq I_c + vx_c - \gamma I_c - \beta I_c$ where βI_c and γI_c are those parts of profit that must go to the entrepreneur and the active bank to assure management effort and monitoring. The active bank supplies funds D_c^m as in (7). The remaining part of external funds must come from standard banks which need to supply a credit $D_c = I_c - A_c - D_c^m$. Substituting this into the binding debt capacity implicitly determines the maximum investment level by $(1+i)(I_c - A_c - D_c^m) = I_c + vx_c - \gamma I_c - \beta I_c$. Multiplying by p, using $p(1+i) = R$, and substituting D_c^m from (7) yields

$$p(vx_c - iI_c) - c^m I_c = p\beta I_c - RA_c, \quad A_c = A - k + \sigma. \tag{8}$$

Proposition 1 ***(Constrained investment)*** *With a binding finance constraint, investment is not driven by the user cost of capital but depends, instead, on pledgeable future income and on accumulated own assets.*

Figure 1 illustrates how investment is determined. The left-hand side of equation (8) is the expected profit and corresponds to the hump-shaped curve. Its maximum gives the virtual unconstrained investment of an innovative firm where no excess return is earned, $vx'_c = i$. The right-hand side of (8) is the 'incentive-line' starting out from the intercept $-A_c R$. The intersection of these two lines implicitely determines the constrained investment level as in (8). At this point, the slopes satisfy $p\,(vx'_c - i) - c^m > p\beta$. In other words, the firm earns an excess return and would like to expand investment but is credit rationed. Financing a higher level of investment with even more external funds would not be incentive compatible.[2] Taking the differential of (4), we can thus state:

Proposition 2 ***(Excess return)*** *Expanding investment of constrained firms would raise expected profit by* $d\pi_c/I_c = \rho$, *where* $\rho \equiv p\,(vx'_c - i) - c^m > 0$ *is the excess return.*

Knowing investment yields the amount of monitoring capital D_c^m in (7) and standard debt $D_c = I_c - A_c - D_c^m$ which is residually obtained from passive banks. The subsidy leaves the firm with more own equity $A_c = A - k + \sigma$ and relaxes the finance constraint by shifting down the 'incentive-line' in Figure 1. A higher price boosts firms' future earnings and also relaxes the finance constraint. It shifts up the expected profit curve so that the intersection occurs at a larger investment scale.

When intermediaries are competitive, firms keep the entire surplus in (3). Even though the surplus is reduced by monitoring costs, it may still be higher than without monitoring.

[2] If firms asked for a marginally larger credit, incentive constraints would be violated, i.e. firms and monitors would shirk and monitoring capital would not be used. Passive banks could still provide credit by discretely raising the loan rate to $i_L > i$ until $(1 + i_L)\,p = R$. Profit v_c^e would discretely fall due to the rise in the loan rate i_L and the loss in the value enhancing contribution of monitoring. We must assume p_L low enough so that firms do not prefer discretely larger credit $I_c^* - A_c$ at i_L, with I_c^* given by $vx'\,(I_c^*) = i_L$. An equilibrium with shirking is definitely not viable if $p_L \to 0$.

To see this, take the differential $d\pi_c = \left[p\left(vx_c' - i\right) - c^m\right] dI_c - I_c dc^m$. The benefit of attracting monitoring capital is that it facilitates investment dI_c because it boosts the firm's pledgeable income by reducing private benefits, $db/dm < 0$, where m measures the monitoring intensity. On the other hand, monitoring adds extra costs $I_c dc^m$. Clearly, if the excess return $p\left(vx_c' - i\right) - c^m$ is positive, the larger feasible investment due to monitoring is worth more than the extra cost $I_c dc^m$. For monitoring to be useful, we must impose an assumption on 'monitoring productivity'.

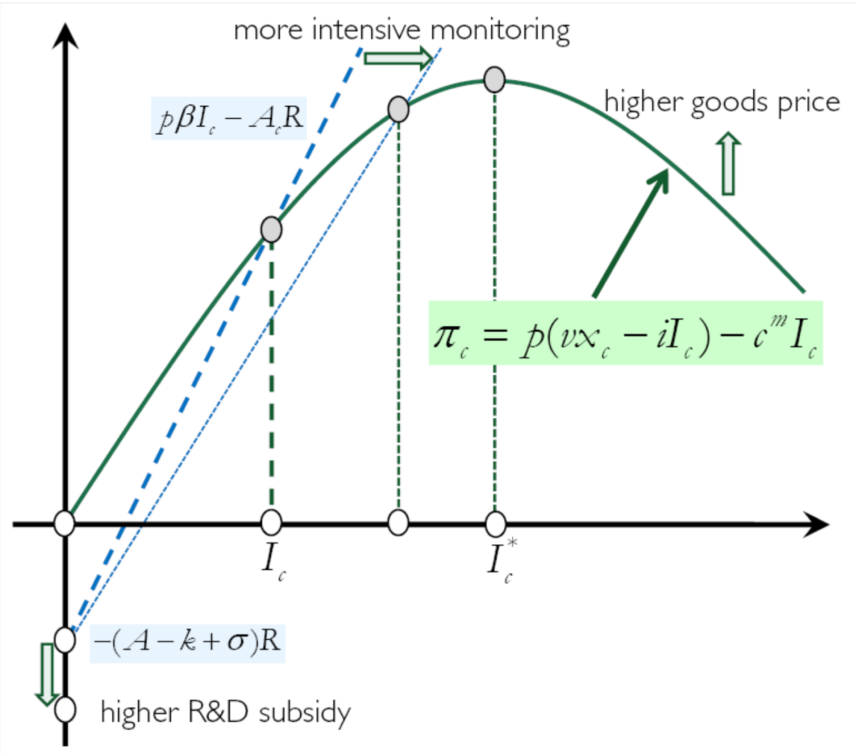

Fig. 1: Finance Constrained Investment

Assumption 2 *Monitoring ($dm = dc^m$) is productive and boosts firm profits:*

$$\rho\lambda > p\beta > \rho \equiv p\left(vx_c' - i\right) - c^m > 0, \quad \lambda \equiv -p\beta' = -\frac{p}{p - p_L}\frac{db}{dm} > 1. \tag{A2}$$

The assumption means that engaging active investors and introcing a small amount of monitoring activity boosts the firm's net present value. To show this, we define the relative increase in marginal monitoring cost by $\hat{c}_m \equiv dc^m/\left(p\beta\right)$, and of monitoring intensity by $\hat{m} \equiv dm/\left(p\beta\right)$. For a given investment level I, a higher monitoring intensity yields a percentage reduction in agency costs of $\hat{b} = -\lambda\hat{m}$ with $\lambda \equiv -p\beta'$, which implies an equally large percentage reduction $\hat{y}^e = -\lambda\hat{m}$ of the minimum, incentive compatible entrepreneurial compensation. Monitoring thereby raises pledgeable income and boosts investment. Using $\hat{\sigma} \equiv d\sigma/k$, the differential of the investment condition gives

$$\hat{I}_c = \frac{pvx_c}{\delta I_c} \cdot \hat{v} + \frac{p\beta}{\delta} \cdot (\lambda\hat{m} - \hat{c}_m) + \frac{AR}{\delta I_c} \cdot \hat{A} + \frac{kR}{\delta I_c} \cdot \hat{\sigma}, \quad \delta \equiv p\beta - \rho < R, \tag{i}$$

where $R > \delta$ assures positive leverage, i.e. $dI_c/dA_c = R/\delta > 1$. Given benefits and costs, monitoring ($\hat{m} = \hat{c}^m$) is desirable only if the net impact on expected profit $\pi_c = p(vx_c - iI_c) - c^m I_c$ is positive, i.e. $d\pi_c = \rho dI_c - I_c dc^m > 0$. Using $\hat{c}_m = \hat{m}$ and δ,

$$d\pi_c = (\rho\lambda - p\beta)\frac{\beta p}{\delta} I_c \cdot \hat{m} > 0. \tag{ii}$$

The condition for monitoring to be attractive is stated by the first inequality in (A2) and consists of two parts: (i) there must be a sufficiently large excess return ρ on investment so that the extra investment created by monitoring leads to a sufficiently large increase in expected profit. Since unconstrained firms do not earn any excess return, they do not benefit from and do not demand monitoring capital since it would only add to costs; and (ii) monitoring must be productive, i.e. the elasticity $\lambda > 0$ must be sufficiently large.

We interpret financial development to mean that active banks get more productive in monitoring, i.e. monitoring intensity m increases relative to an unchanged marginal cost c^m. Since more intensive monitoring reduces private benefits of entrepreneurs, $\beta' < 0$, the incentive line in Figure 1 becomes flatter and rotates clockwise around the intercept. In reducing the entrepreneur's incentive compatible income, monitoring boosts the firm's debt capacity and leads to a larger level of investment.

Innovative firms have little own assets and large investment opportunities and are heavily reliant on external funds. Being constrained, they benefit from monitoring which improves access to capital and allows them to invest more. Since active finance is more costly, firms raise only the minimum amount necessary to guarantee monitoring, and obtain the remaining credit from standard banks. Firms thus finance themselves from multiple sources. The more productive monitoring is, the more external funds firms can raise, and the closer they come to the unconstrained regime. We consider only a marginal increase in monitoring productivity so that credit constraints are only partly relaxed and innovative firms are still rationed. Standard, less innovative firms have relatively large own assets and few investment opportunities. They are thus able to finance the first-best investment level and earn no more than the normal return on capital.

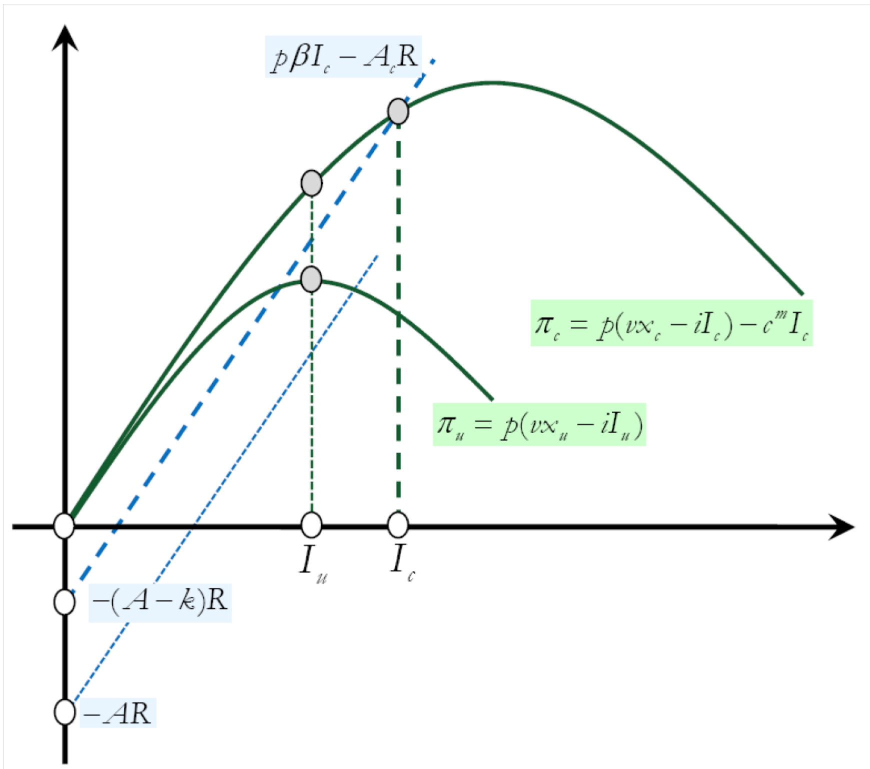

Fig. 2: Constrained and Unconstrained Firms

Figure 2 compares investment and profit of constrained and unconstrained firms. Expected profit of innovative firms is larger at every level of investment, investment of unconstrained firms maximizes expected value since the incentive constraint is slack, and investment of innovative firms is constrained. As illustrated in Figure 2, we impose parameter restrictions such that innovative firms invest at a larger scale, $I_c > I_u$.[3]

[3]Suppose monitoring is absent. For a given price v, we restrict parameters k, A, θ and β such that (i) standard firms are unconstrained; (ii) innovative firms are constrained; and (iii) invest more than standard firms, $I_c > I_u$; and (iv) only a share of firms innovate ($0 < q < 1$). Introducing monitoring makes innovative firms, by (A2), invest even more but $\lambda \to 1$ reduces the viability of monitoring so that innovative firms will still be constrained.

Stage i, R&D: Initially, firms are assumed to be heterogeneous in their innovation potential which is measured by the success probability of early stage R&D investment. After making a draw q' from the distribution $G(q)$, the firm learns the early stage success probability of its project and chooses the level of R&D spending, $k_j \in \{0, k\}$. The private cost is possibly subsidized by government. Firms with a type q' project invest in R&D if $q'\pi_c - (k - \sigma) R \geq q'\pi_u$, giving the cut-off

$$q = (k - \sigma) R / (\pi_c - \pi_u) . \tag{9}$$

Figure 3 illustrates how discrete innovation choice splits the entrepreneurial sector into innovative and standard firms. Types $q' < q$ strictly prefer to avoid R&D spending while types $q' > q$ invest in R&D which turns them into highly productive growth companies.

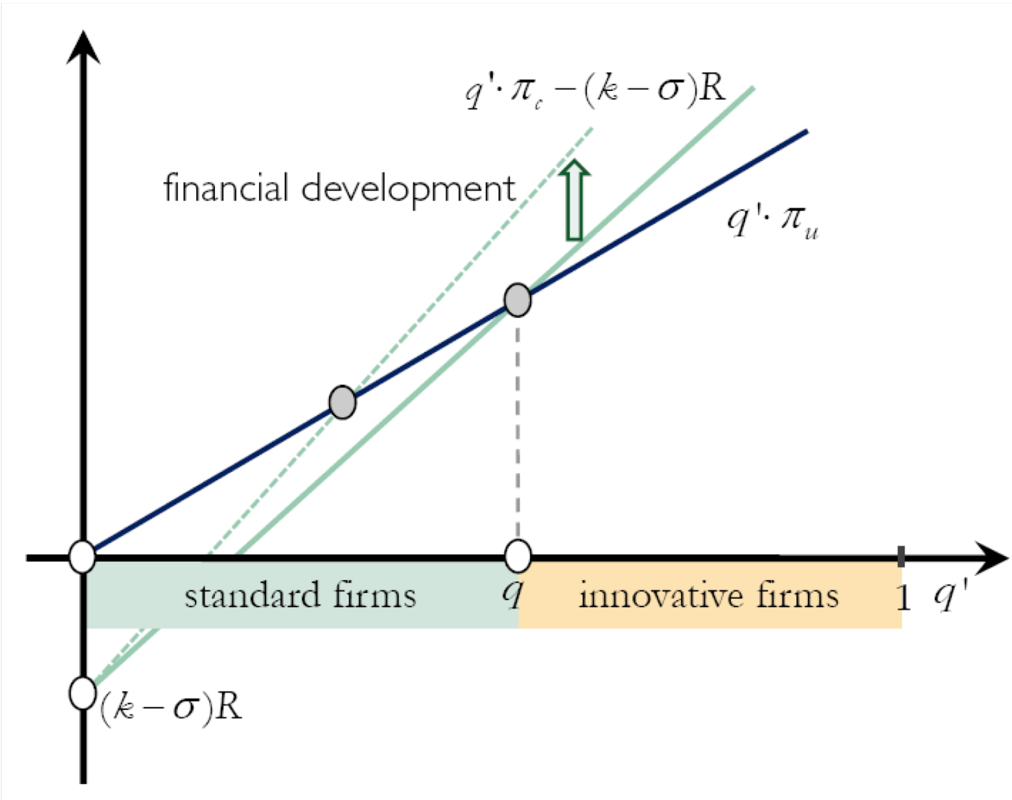

Fig. 3: Innovation Decision

Ex ante, before the type of project is revealed, firms innovate with probability s_k and survive the early stage with probabilities s_c, s_u:

$$s_c = \int_q^1 q' dG(q') , \quad s_u = \int_0^q q' dG(q') , \quad s_k = \int_q^1 dG(q') . \tag{10}$$

Expected profit ex ante, anticipating R&D and expansion investments, amounts to

$$\pi_E = s_u \pi_u + s_c \pi_c - (k - \sigma) R s_k > 0. \tag{11}$$

From E firms in the entrepreneurial sector, $s_k E$ engage in R&D, $s_j E$ survive the early stage and $p s_j E$ produce output. Hence, more and more firms get eliminated over firms' life-cycle. Expected profit $\pi_E = \int_0^1 \pi_u q' dG(q') + \int_q^1 [(\pi_c - \pi_u) q' - (k - \sigma) R] dG(q')$ is positive since $\pi_c > \pi_u > 0$, and reflects a rent on entrepreneurial ability. The square bracket is zero for the cut-off q but strictly positive for $q' > q$.

3.3 General Equilibrium

Equilibrium reflects individually optimal behavior, a binding fiscal budget, and market clearing in loanable funds and sectoral output markets. By Walras' Law, one of these conditions is implied by the others. Consider first equilibrium in the loanable funds market such that supply of funds equals demand,

$$A(1 - E) + A_c (s_k - s_c) E + A_u (1 - s_k - s_u) E = \sum_j (I_j - A_j) s_j E + Z + \sigma s_k E.$$

The supply of loanable funds on the left hand side consists of (i) savings of $1-E$ investors; (ii) residual savings $A_c = A - k + \sigma$ of failed innovative firms; and (iii) residual savings $A_u = A$ of failed standard firms. Demand on the right hand side includes (i) loans for expansion investments of both types of firms; (ii) investment in the safe Z-technology; and (iii) government debt issued to finance upfront R&D subsidies. Rearranging yields

$$A = Z + K \cdot E, \quad K \equiv s_k k + \bar{I}, \quad \bar{I} \equiv \sum_j s_j I_j, \tag{12}$$

where K denotes average investment per firm, consisting of R&D and expansion investment, and Z is residual investment in the Ricardian sector.

At the beginning, $s_k E$ innovating firms receive an R&D subsidy. At the end of period, the government collects a per capita lump-sum tax T from workers. Since tax revenue accrues at the end, the government raises funds $\sigma s_k E$ on the deposit market to subsidize innovating firms, and pays back $\sigma s_k ER$. The fiscal budget is

$$TL = \sigma \cdot s_k ER. \tag{13}$$

End of period wealth is $y_I = AR$, $y_E = AR + \pi_E$ and $y_L = 1 - T$ for investors, entrepreneurs and workers, respectively. Financial intermediaries are competitive and make zero profits on average. The intermediation margin of active banks must cover not only the cost of credit defaults but also monitoring cost. These banks break even with $p(1+i^m)D^m - RD^m = c^m I_c$ per project where the right hand side is the cost of hiring monitors which reduces sector 2 output. Total income is $Y = \pi_E E + AR + y_L L$. Define average values by $\bar{x} \equiv \sum_j s_j x_j$, and similarly for $\bar{I}$. Substituting π_E and π_j and the fiscal constraint yields aggregate income $Y = \left[\left(\bar{I} + v\bar{x}\right)p - \bar{I}R - c^m s_c I_c - k s_k R\right]E + AR + L$. Use now the capital market condition (12), define sectoral outputs X_E and X_N, and note the consumer budget in (1) to get the income expenditure identity,

$$C_N + vC_E = Y = vX_E + X_N, \quad X_E \equiv \bar{x}pE, \quad X_N \equiv L + ZR + \bar{I}pE - c^m s_c I_c E. \tag{14}$$

The income identity reflects balanced trade, $(C_N - X_N) + v(C_E - X_E) = 0$.

Arbitrage and linearity of the Ricardian investment technology fixes the deposit factor R and the loan rate i by (4). Innovative sector investment $\bar{I}$ is determined by interest rates and a world relative price v. Equilibrium in the loanable funds market thus residually determines investment Z in the standard sector. Innovation choice fixes the composition of firms in the entrepreneurial sector as is reflected in the s-probabilities which pins down the supply side given that E is exogenous. Computing aggregate income Y yields the demand side and the trade balance. World market clearing for the innovative good fixes the relative price v. Finally, Walras' law implies equilibrium in the world market for standard goods. In a closed economy, v clears the innovative goods market $C_E = X_E$, and market clearing in the standard sector follows by Walras' law.

As a benchmark, we state the *first-best, unconstrained equilibrium.* When private benefits are small and own assets after innovation are large, then $y_c^e(I_c) > I_c B/\nabla$ in part

(ii) of Assumption 1. Monitoring is not useful and not demanded so that $c^m = 0$. The only change is that investment and profits of innovative firms are now given by

$$v\theta f'(I_c) = i, \quad \pi_c = p(vx_c - iI_c). \tag{6'}$$

The excess return is zero, $\rho = 0$. All other elements of the equilibrium are unchanged.

4 Small Open Economy

In this section, we study how three distinct areas of policy intervention, import protection, R&D subsidies and financial development, can shape the trade structure and affect welfare in a small open economy. When analyzing import protection, we assume the country to be an importer of innovative goods.[4] Buyer arbitrage links domestic and foreign prices by $v = \tau v^*$ where $\tau \geqslant 1$ is a measure of non-tariff barriers. A small open economy cannot affect the common world price v^* of the innovative good in all other countries. Hence, import protection raises the domestic price by $\hat{v} = \hat{\tau}$. When studying the R&D subsidy, we assume the initial equilibrium to be untaxed, i.e. $\sigma = T = 0$ at the outset, which avoids complicated tax base effects.

4.1 Firm Level Adjustment

Standard and innovative firms react in different ways to economic shocks. Standard firms are unconstrained. Given that interest rates are pinned down in the Ricardian sector, investment in (6) exclusively depends on the output price. Using $x_j = \theta_j (I_j)^\alpha$,

$$\hat{I}_u = \varepsilon \cdot \hat{v}, \quad d\pi_u = pvx_u \cdot \hat{v}, \quad \varepsilon \equiv \frac{-x'(I_j)}{I_j x''(I_j)} = \frac{1}{1-\alpha}. \tag{15}$$

A higher price boosts investment and profits of standard firms, where the change in profits reflects the envelope theorem.

[4] If the country were an exporter, we could investigate an export tax to raise the domestic price.

By way of contrast, constrained investment is determined by a firm's debt capacity in (8) which follows from binding incentive compatibility conditions. In contrast to neoclassical theory, investment is not driven by the real user cost of capital but rather depends on the determinants of pledgeable income, such as the level of monitoring, and on own assets A_c as a measure of financial strength. For example, improvements in the banking sector may result in better oversight of firms which reduces incentive compatible entrepreneurial compensation and strengthens pledgeable income. We interpret financial development as an increase in monitoring productivity of active banks, given a fixed marginal cost c_m. The investment response of constrained firms is stated in equation (i) following (A2). To compare with the unconstrained case, we rewrite this condition as

$$\hat{I}_c = (\varepsilon + \phi_v) \cdot \hat{v} + \phi_\sigma \cdot \hat{\sigma} + \phi_m \cdot \hat{m}, \tag{16}$$

where coefficients are defined as

$$\phi_v \equiv \frac{vpx_c}{\delta I_c} - \varepsilon, \quad \phi_\sigma \equiv \frac{kR}{\delta I_c}, \quad \phi_m \equiv \frac{\lambda p \beta}{\delta}.$$

Setting ϕ-coefficients to zero recovers the unconstrained case where investment is independent of R&D subsidies and monitoring, leaving $\hat{I}_c = \varepsilon \hat{v}$ as with standard firms.

A higher price stimulates investment of constrained firms as well although the price elasticity is generally not the same. The mechanism, however, is entirely different. The stimulus comes from the increased cash-flow and not from the change in the real user cost of capital. Financial sector development in terms of higher monitoring productivity also raises the firm's pledgeable income and debt capacity and thereby boosts investment by facilitating access to external credit. Since monitoring cannot play a useful role when firms are unconstrained, it does not affect standard firm investment. Finally, the R&D subsidy strengthens the firm's own equity after R&D spending, thereby relaxes the finance constraint and boosts expansion investment. This is a novel role for R&D subsidies! The direct effect of the subsidy is to reduce private R&D cost and stimulate innovation (on the extensive margin, see below). However, the subsidy also helps innovative firms to better exploit the productivity gains from innovation and the associated investment opportunities which earn an above normal, excess return. Since the R&D subsidy is already sunk at the expansion stage, this second effect does not exist when firms are unconstrained.

Unlike in the neoclassical case, constrained firms earn an excess return since they are unable to fully exploit investment opportunities. For this reason, profits with higher investment levels, $d\pi_c = pvx_c \cdot \hat{v} + \rho I_c \cdot \hat{I}_c$. Relaxing the finance constraint and boosting investment yields additional profit in proportion to the excess return ρ net of marginal monitoring cost.[5] Substituting the investment response gives

$$d\pi_c = [pvx_c + \rho I_c (\varepsilon + \phi_v)] \cdot \hat{v} + \rho I_c \phi_\sigma \cdot \hat{\sigma} + \rho I_c \phi_m \cdot \hat{m}. \tag{17}$$

The R&D subsidy boosts profit ex ante, net of the subsidy as in (11), but does not directly change profits π_j in the expansion stage. Nevertheless, the subsidy indirectly boosts profit since it relaxes the finance constraint and allows the firm to invest more at an above average, excess return.

Any policy that strengthens expected profits of innovative firms relative to others leads more firms at an early stage to pursue an innovation strategy. Directly subsidizing the R&D cost similarly boosts innovation. Evaluating the changes at the untaxed equilibrium with $\sigma = 0$, the impact on the innovation threshold is $\hat{q} = -(d\pi_c - d\pi_u) / (\pi_c - \pi_u) - \hat{\sigma}$ which yields $\hat{q} = -pv\frac{x_c - x_u}{\pi_c - \pi_u}\hat{v} - \frac{\rho I_c}{\pi_c - \pi_u}\hat{I}_c - \hat{\sigma}$. The second term would not be present in the first best. In this case, the subsidy would shift up the profit line net of R&D cost of an innovative firm in Figure 3 (not drawn), leading to a lower innovation threshold. When firms are constrained, the subsidy additionally boosts investment and strengthens profits, thereby rotating the profit line to the left and inducing even more innovation. The Figure also illustrates the effect of financial development on innovation. Since monitoring is useful only when firms are constrained, it cannot play a role in the first best equilibrium. However, since a higher monitoring intensity boosts the debt capacity of constrained

[5] Setting $\rho = 0$ recovers the unconstrained case. Firms would not want monitoring capital on top of passive bank credit so that $c^m = 0$. The impact on profit would be as in (15) since unrestricted investment drives down the excess return to $\rho = 0$. By the envelope theorem, a variation of investment does not affect profits of unconstrained firms with a normal return on capital.

firms, it facilitates larger investments with an above normal return and thereby selectively strengthens profits of innovative relative to standard firms. As shown in Figure 3, the profit line net of R&D cost rotates to the left and thereby lowers the innovation threshold. Formally, by substituting the investment response in (16), we find a change in the cut-off probability equal to

$$\hat{q} = -\mu_v \cdot \hat{v} - \mu_\sigma \cdot \hat{\sigma} - \mu_m \cdot \hat{m}, \tag{18}$$

where all coefficients are defined in positive values,

$$\mu_v \equiv \frac{pv(x_c - x_u) + \rho(\varepsilon + \phi_v) I_c}{\pi_c - \pi_u}, \quad \mu_\sigma \equiv 1 + \frac{\rho \phi_\sigma I_c}{\pi_c - \pi_u}, \quad \mu_m \equiv \frac{\rho \phi_m I_c}{\pi_c - \pi_u}.$$

A declining threshold means that more firms innovate. All three shocks boost innovation at the extensive margin, but only import protection and the R&D subsidy would do so in a first best world. Monitoring capital would not be demanded and would not exist if none of the firms were constrained. When more firms adopt an innovation strategy, the share of high productivity firms rises, and so does average productivity in the industry.[6] To evaluate welfare consequences, we also need to know the change in expected profit ex ante, taking account of R&D costs as well. Since compositional effects are related by $q ds_k = ds_c = -ds_u$, average profit in (11) rises by $d\pi_E = s_u d\pi_u + s_c d\pi_c + s_k R d\sigma + [(\pi_c - \pi_u) q - (k - \sigma) R] ds_k$, where $\sigma = 0$ initially. The square bracket is zero by discrete R&D choice in (9). Noting $\bar{x} = \sum_j s_j x_j$, expected profit ex ante changes by

$$d\pi_E = [pv\bar{x} + \rho s_c I_c (\varepsilon + \phi_v)] \cdot \hat{v} + [s_k k R + \rho s_c I_c \phi_\sigma] \cdot \hat{\sigma} + \rho s_c I_c \phi_m \cdot \hat{m}. \tag{19}$$

4.2 Supply, Demand and Welfare

We now show how firm level investment and innovation determines sectoral supply, national income and demand. Aggregate supply $X_E = \bar{x} p E$ changes in proportion to

[6] Average productivity $\theta_E = \frac{s_c}{s_c + s_u}\theta + \frac{s_u}{s_c + s_u}$. Since $s_c + s_u$ is a constant, innovation ($\hat{q} < 0$) yields raises average productivity in the industry by $d\theta_E = -(\theta - 1)\frac{q^2 g(q)}{s_c + s_u} \cdot \hat{q}$.

$\bar{x} = s_c x_c + s_u x_u$ which is a measure of average output of innovative and standard firms. Out of E firms initially, only a share $s_c + s_u = \int_0^1 q' dG(q')$ survives the early stage and p of those make it to the mature production stage. Noting the compositional effects $ds_c = -ds_u = -qg(q)\,dq$ as a result of innovation choice, average output changes by $d\bar{x} = s_c dx_c + s_u dx_u - (x_c - x_u)\, qg(q)\, dq$, or

$$\hat{X}_E = \zeta_{x,v} \cdot \hat{v} + \zeta_{x,\sigma} \cdot \hat{\sigma} + \zeta_{x,m} \cdot \hat{m}, \tag{20}$$

where output elasticities are all positive and $\alpha = I_j x_j' / x_j$,

$$\begin{aligned}
\zeta_{x,v} &\equiv \alpha \left(\varepsilon + \frac{s_c x_c}{\bar{x}} \phi_v \right) + \frac{x_c - x_u}{\bar{x}} q^2 g(q)\, \mu_v, \\
\zeta_{x,\sigma} &\equiv \alpha \frac{s_c x_c}{\bar{x}} \phi_\sigma + \frac{x_c - x_u}{\bar{x}} q^2 g(q)\, \mu_\sigma, \\
\zeta_{x,m} &\equiv \alpha \frac{s_c x_c}{\bar{x}} \phi_m + \frac{x_c - x_u}{\bar{x}} q^2 g(q)\, \mu_m.
\end{aligned}$$

Aggregate supply reflects intensive and extensive margins. A higher price for innovative goods, for example, boosts investment and output of both types of firms. This intensive margin is related to the first part of the ζ-elasticities. Further, a higher price induces more firms to innovate. For each firm that is turned from a standard producer into a highly productive growth company, output rises by the difference in output levels $x_c - x_u$, times the mass of firms moving to a higher productivity level. An R&D subsidy, raises investment of constrained firms by ϕ_σ, translates into higher output $\alpha\phi_\sigma$ per firm. Since the subsidy stimulates investment only of constrained innovative firms, the average output gain is scaled by the share $s_c x_c / \bar{x}$. In a first best, the subsidy does not affect investment ($\phi_\sigma = 0$) and output on the intensive margin but it still boosts innovation ($\mu_\sigma = 1$) and aggregate output on the extensive margin. Financial sector development can play no role at all in the first best (both $\phi_m = \mu_m = 0$).

National income consists of capital income of investors and entrepreneurs plus wage income of workers, $Y = AR + \pi_E E + (1 - T) L$. Using the fiscal constraint and starting from an untaxed equilibrium, it changes by $dY = E d\pi_E - s_k E R d\sigma$. Substituting the change in expected profits of a new firm in (19) yields

$$\hat{Y} = \left(\eta_s + \zeta_{y,v} \right) \cdot \hat{v} + \zeta_{y,\sigma} \cdot \hat{\sigma} + \zeta_{y,m} \cdot \hat{m}, \quad \eta_s \equiv \frac{v X_E}{Y}, \quad \eta_i \equiv \frac{s_c I_c}{v p \bar{x}}, \tag{21}$$

where η_s is the GDP share of the innovative sector and coefficients are defined as

$$\zeta_{y,v} \equiv \rho\eta_i\eta_s\left(\varepsilon + \phi_v\right), \quad \zeta_{y,\sigma} \equiv \rho\eta_i\eta_s\phi_\sigma, \quad \zeta_{y,m} \equiv \rho\eta_i\eta_s\phi_m.$$

We also use η_i for the share of constrained investment in the expected value of output per firm. Note how the excess return ρ magnifies income gains. In the first-best, $\rho = 0$ and $\hat{Y} = \eta_s \cdot \hat{v}$. The impact of R&D subsidies or financial development arises only via the effect on finance constraints. These policies thus help to implement additional investments with an above normal rate of return while the alternative use of resources in the standard sector, i.e. $Z = A - \left(s_k k + \bar{I}\right) E$ in (12), would only earn a normal return, giving ZR at the end of period. The income gains are, thus, proportional to the excess return ρ earned by constrained firms in the innovative sector.

Assuming constant expenditure shares in (1), the demand allocation is $vC_E = \eta Y$. Using the change in national income in (21), this yields

$$\hat{C}_E = \hat{Y} - \hat{v} = -\left(1 - \eta_s - \zeta_{y,v}\right) \cdot \hat{v} + \zeta_{y,\sigma} \cdot \hat{\sigma} + \zeta_{y,m} \cdot \hat{m}. \tag{22}$$

Without a finance constraint ($\rho = 0$), a higher price shrinks demand by $\hat{C}_E = -\left(1 - \eta_s\right)\hat{v}$. The demand reduction is weakened by the income gains that arise when constrained firms are able to expand investment. These gains are proportional to the excess return earned by R&D intensive firms. In the first best, the R&D subsidy would not affect consumption, i.e. the gains to firms are completely offset by taxes, and neither would financial development be useful when firms are unconstrained.

A country's trade structure and comparative advantage depends on the behavior of excess demand, $\zeta \equiv C_E - X_E$. Defining $\hat{\zeta} \equiv vd\zeta/Y$ yields $\hat{\zeta} = \eta\hat{C}_E - \eta_s\hat{X}_E$, or

$$\hat{\zeta} = -\zeta_v \cdot \hat{v} - \zeta_\sigma \cdot \hat{\sigma} - \zeta_m \cdot \hat{m}, \tag{23}$$

where coefficients are, after substitution,

$$\begin{aligned}
\zeta_v &\equiv \left(1 - \eta_s - \zeta_{y,v}\right)\eta + \zeta_{x,v}\eta_s > 0, \\
\zeta_\sigma &\equiv \zeta_{x,\sigma}\eta_s - \zeta_{y,\sigma}\eta = \left[\frac{s_c x_c \alpha}{\bar{x}} - \rho\eta\eta_i\right]\phi_\sigma\eta_s + \frac{x_c - x_u}{\bar{x}} q^2 g\left(q\right)\mu_\sigma\eta_s > 0, \\
\zeta_m &\equiv \zeta_{x,m}\eta_s - \zeta_{y,m}\eta = \left[\frac{s_c x_c \alpha}{\bar{x}} - \rho\eta\eta_i\right]\phi_m\eta_s + \frac{x_c - x_u}{\bar{x}} q^2 g\left(q\right)\mu_m\eta_s > 0.
\end{aligned}$$

As long as ρ is not too large, $1-\eta_s > \zeta_{y,v}$ must hold which implies $\zeta_v > 0$.[7] As long as the square bracket is positive, the other coefficients are positive as well. To see this, use $\alpha = I_c x_c'/x_c$, $\eta_i = s_c I_c/(vp\bar{x})$ and $\rho = p(vx_c' - i) - c^m$,

$$\frac{s_c x_c \alpha}{\bar{x}} - \rho\eta\eta_i = [vpx_c' - \rho\eta]\,\eta_i = [(1-\eta)\,vpx_c' + \eta\cdot(ip + c^m)]\,\eta_i > 0.$$

A higher relative price reduces excess demand and, thereby, imports of innovative goods. A higher (tax financed) R&D subsidy has the same effect although it appears ambiguous a priori since the subsidy also boosts income and demand which raises the trade deficit. However, the supply effect clearly dominates. The same holds for monitoring intensity which expands investment and supply and thereby reduces excess demand.

In equilibrium, entrepreneurs do not consume private benefits and active banks do not divert monitoring activities. Agents are compensated with sufficiently high income stakes to prevent both types of shirking. Welfare is equal to real income, $U = Y/v_D$, where v_D is the price index and changes by $\hat{U} = \hat{Y} - \eta\hat{v}$, giving

$$\hat{U} = [\rho\cdot\eta_i\eta_s(\varepsilon + \phi_v) - (\eta - \eta_s)]\cdot\hat{v} + \rho\cdot\eta_i\eta_s\phi_\sigma\cdot\hat{\sigma} + \rho\cdot\eta_i\eta_s\phi_m\cdot\hat{m}. \tag{24}$$

In the first best, $\hat{U} = -(\eta - \eta_s)\,\hat{v}$, i.e. a higher price reduces welfare of an import country with $\eta > \eta_s$ on account of a negative terms of trade effect. However, a higher price strengthens pledgeable income, relaxes finance constraints and allows firms in the innovative sector to realize unexploited investment opportunities with strictly positive net value. This magnifies national income in proportion to the excess return where the gain is weighed by the investment share of constrained firms in total output times the GDP share of the innovative sector, and also depends on the strength of the investment response. When the output price is given in a small open economy, an R&D subsidy boosts welfare since it relaxes the finance constraint. It thereby strengthens income by helping to exploit more investment opportunities with an excess return. Financial sector maturation, as measured by a higher monitoring productivity m, improves firms' access

[7] In the first best, $\rho = \phi_j = \mu_m = 0$ and $\mu_\sigma = 1$, leaving $\zeta_m = 0$, $\zeta_\sigma = \frac{x_c - x_u}{\bar{x}} q^2 g(q)\,\eta_s$ and $\zeta_v \equiv (1-\eta_s)\,\eta + \left[\alpha\varepsilon + \frac{x_c - x_u}{\bar{x}} q^2 g(q)\,\mu_v\right]\eta_s$ with $\mu_v \equiv \frac{pv(x_c - x_u)}{\pi_c - \pi_u}$.

to external finance and boosts investment and profits. Financial development similarly raises welfare in proportion to ρ.

4.3 Policy Intervention

The following propositions summarize the consequences of seemingly different areas of policy intervention in a small open economy. The statements can be verified by the comparative static results in the preceding two subsections. We first turn to classical trade policy, consisting here of protection by raising non-tariff trade barriers. Protection in an import country raises the domestic price of the innovative good and leads to

Proposition 3 ***(Protection)*** *In a small open economy, a higher price boosts investment and output of all firms in the innovative sector, but disproportionately raises profits of constrained firms. It thereby induces more innovation, strongly expands aggregate supply and reduces the trade deficit of the innovative sector. If the trade deficit is small, national welfare rises in proportion to the excess return on investment of constrained firms.*

With a small trade deficit, i.e. $\eta \approx \eta_s$, the negative terms of trade effect of a higher price in an import country is also small, yielding a welfare gain from relaxing finance constraints. This result might justify a small level of protection to help 'infant industries' with many constrained firms that are unable to fully exploit their growth opportunities. The existence of finance constraints might be rooted in weak institutions like bad accounting rules, weak investor protection and other weaknesses in corporate governance. These shortcomings allow for managerial discretion and autonomy (high value of β), require large financial incentives to incentivize entrepreneurs and narrow down pledgeable income and the financing capacity of firms. They could also be due to a rather immature financial sector with little effective monitoring and oversight of firms which again restricts access to external funding. While at least a small degree of protection might help to relax finance constraints and yield welfare gains, there might be other policies aiming more directly at the root of the problem. One possibility is an R&D subsidy which strengthens residual own assets and thereby helps innovative firms to gain access to external funding and to exploit their investment opportunities to a larger extent.

Proposition 4 ***(R&D subsidy)*** *In a small open economy with a fixed output price, an R&D subsidy relaxes the finance constraint and stimulates investment, output and (expansion stage) profits of innovative firms while non-innovating firms are not affected. The subsidy boosts innovation and thereby raises the share of growth companies in the innovative sector. Aggregate supply expands on intensive and extensive margins and reduces the trade deficit in R&D intensive goods. National welfare rises in proportion to the excess return on investment of constrained firms.*

Whereas trade protection raises the output price and thereby stimulates investment of both R&D intensive and standard firms in the innovative sector, the R&D subsidy is specifically targeted on finance constrained firms which are most in need of a subsidy in order to implement more projects with a strictly above normal rate of return. However, the aggregate implications are similar.

Finally, we turn to financial sector development, meaning that active banks learn to monitor firms more effectively without any increase in the marginal cost of monitoring. The emergence of specialized intermediaries such as investment banks, venture capitalists or 'Hausbanken' with close ties to their client firms is driven by the existence of constrained firms. The role of these intermediaries is to improve access to the capital market by monitoring firms, containing possible managerial misbehavior and, thereby, raising a firm's debt capacity. These banks perform a certification role. Observing that a firm attracts financing from an active investment bank, other more passive banks can trust in good corporate governance and will be able to lend more as well. By this mechanism, financial sector maturation improves access to external financing and facilitates investment of constrained, innovative firms. Obviously, unconstrained firms have no problem in raising external funds and therefore do not demand monitoring capital. Financial development is inconsequential for these firms.

Proposition 5 ***(Financial development)*** *In a small open economy with a fixed output price, a higher monitoring productivity relaxes the finance constraint and stimulates investment, output and (expansion stage) profits of innovative firms while non-innovating firms are not affected. The subsidy boosts innovation and thereby raises the share of growth companies in the innovative sector. Aggregate supply expands on intensive and extensive margins and reduces the trade deficit in R&D intensive goods. National welfare rises in proportion to the excess return on investment of constrained firms.*

We have discussed three rather different policy areas that could boost welfare in a small open economy when part of innovative sector firms are financially constrained. Can these policies be compared in any way? Given a certain improvement in financial sector efficiency, as measured in terms of monitoring intensity, what is the size of the R&D subsidy and of trade protection that would yield the same welfare gains?

Proposition 6 ***(Relative policy effectiveness)*** *In a small open economy with a small trade deficit in innovative goods, protection, R&D subsidies and financial sector development have equivalent effects on constrained investment and on national welfare, if the shocks are related by* $vpx_c\hat{v} = kR\hat{\sigma} = p\beta I_c\lambda\hat{m}$.

First note that this statement excludes terms of trade effects by assuming balanced trade, i.e. $\eta = \eta_s$. The aim is to understand how protection affects financial frictions by raising the domestic price and not mix the welfare gains with terms of trade effects. However, in our model with homogeneous goods, protection is relevant only when the country is an importer. The proposition thus assumes an 'infinitesimally small' trade deficit in innovative goods so that consumer arbitrage leads to an increase in the domestic price as a result of protection. Given this qualification, and dividing the relationship by δI_c yields $(\varepsilon + \phi_v)\,\hat{v} = \phi_\sigma\hat{\sigma} = \phi_m\hat{m}$ and, thus, equally large effects of the three alternative policies on constrained firm investment, see (16), and on national welfare, see (24).

To obtain a more quantitative interpretation of the policy shocks, note that $y^e = \beta I_c$ is the entrepreneur's minimum incentive compatible income which can be reduced with more effective monitoring by $\hat{y}^e = -\lambda\hat{m}$, see the analysis following (A2). Consider now an increase in monitoring intensity that leads to a one percentage point reduction in the entrepreneur's incentive income, i.e. $\lambda\hat{m} = 1$. Given the above relationship, an equally sized welfare gain could be achieved with an R&D subsidy equal to $\hat{\sigma} = py^e/kR$ or $d\sigma = py^e/R$ which is the discounted value of the expected entrepreneurial income. Alternatively, given that protection raises the domestic price by $\hat{v} = \hat{\tau}$, the welfare equivalent level of tariff protection is $\hat{\tau} = y^e/(vx_c)$ which is the entrepreneur's incentive income as a share of the sales value of the firm. Observe, however, that this policy equivalence does not carry over to innovation or aggregate supply. Looking at the change in the innovation threshold in (18) shows that the R&D subsidy boosts innovation more than financial sector development since the subsidy boosts innovation even in the absence of financial frictions while more intensive monitoring does not. A similar argument applies to a protection induced price increase.

5 Large Open Economies

In a large open economy, a supply side expansion reduces the world price of innovative goods which feeds back negatively on the domestic economy since a lower price erodes the financing capacity of constrained firms and leads to a counterveiling welfare effect. In analyzing world equilibrium, we assume the home country to be an importer of innovative goods so that the rest of the world in total must be exporting, although each individual foreign country may be an importer or an exporter. When the home economy is importing innovative goods, the price at home rises with import protection, $v = \tau v^*$, relative to the common world price v^* in all other countries, where $\tau = 1$ and $v = v^*$ at the outset. Equilibrium in the world market requires $d\zeta + \sum_j d\zeta^j = 0$ where ζ^j is excess demand in other countries. Multiply by $v = v^*$, divide by world GDP, use country j's GDP share by $\omega^j \equiv Y^j/(Y + \sum_j Y^j)$, implying $\omega + \sum_j \omega^j = 1$, and define $\hat{\zeta}^j \equiv v^* d\zeta^j/Y^j$. The condition $\hat{\zeta}^* \equiv \omega\hat{\zeta} + \sum_j \omega^j \hat{\zeta}^j = 0$ for global market clearing pins down the impact on the common price. Protection relates domestic and foreign prices by $\hat{v} = \hat{v}^* + \hat{\tau}$. Using this, domestic excess demand changes by $\hat{\zeta} = -\zeta_v (\hat{v}^* + \hat{\tau}) - \zeta_\sigma \hat{\sigma} - \zeta_m \hat{m}$, while excess demand in foreign countries changes by $\hat{\zeta}^j = -\zeta_v^j \cdot \hat{v}^*$ which yields

$$\hat{v}^* = -\omega \frac{\zeta_v}{\zeta_v^*} \cdot \hat{\tau} - \omega \frac{\zeta_\sigma}{\zeta_v^*} \cdot \hat{\sigma} - \omega \frac{\zeta_m}{\zeta_v^*} \cdot \hat{m}, \quad \zeta_v^* \equiv \omega \zeta_v + \sum_j \omega^j \zeta_v^j, \tag{25}$$

where ζ_v^* is the GDP weighted average of individual country elasticities. The small open economy case results if the number of countries n gets large. This is most easily seen in the symmetric case where $\zeta_v^* = \omega n \zeta_v$, leading to $\hat{v} = -(\zeta_\sigma / (n\zeta_v)) \hat{\sigma}$. As $n \to \infty$ (implying $\omega \to 0$), an isolated shock in the domestic economy has only a negligible impact on the world market price. In a closed economy with $n = \omega = 1$, protection is irrelevant and the equilibrium price follows from $\hat{\zeta} = 0$ in (23).

5.1 Protection

If the home economy introduces non-tariff import barriers, it raises the domestic price above the world price level, $\hat{v} = \hat{v}^* + \hat{\tau}$. The trade deficit shrinks which creates excess supply on the world market and depresses the world price, see (25). Since $\omega\zeta_v/\zeta_v^* < 1$, the domestic price increases, but less than in a small open economy,

$$\hat{v} = (1 - \omega\zeta_v/\zeta_v^*) \cdot \hat{\tau} > 0. \tag{26}$$

Protection raises the domestic price. Proposition 3 still applies, i.e. protection relaxes finance constraints and induces a supply expansion. If the trade deficit in innovative goods is small, the home country gains from a small degree of protection.

We can now state the spillovers on foreign economies. Since all shocks by assumption occur at home, foreign countries are only affected by a change in the common price v^*. Replacing v by v^* in Section 3 yields the adjustment in a foreign country j.[8]

[8] The international welfare results from protection are similar to Egger and Keuschnigg (2010). That paper did not consider an explicit innovation decision and the coexistence of constrained and unconstrained firms in the innovative sector. Further, the analysis of trade implications of R&D subsidies and the discussion of financial sector development is new in the present paper.

Proposition 7 ***(Protection spillovers)*** *(a) Domestic protection reduces the common world price v^* and thereby retards foreign investments I_c^j and I_u^j, discourages foreign innovation by raising the cut-off values q^j, and reduces (magnifies) foreign trade surpluses (deficits). (b) Domestic protection tightens foreign finance constraints. Welfare of foreign export nations strongly falls since the negative terms of trade effect is reinforced by tightening finance constraints. Welfare of foreign import nations changes ambiguously since the positive terms of trade effect may be offset by firms becoming more finance constrained.*

The interplay between welfare effects from terms of trade changes and financial frictions can generate interesting results on world welfare that would not be possible if firm level investment were first-best in all countries. One interesting possibility is:

Proposition 8 ***(World welfare)*** *If (i) all countries are close to autarky and terms of trade effects are small and if (ii) the home economy is finance constrained while foreign economies are not, domestic protection raises world welfare.*

With terms of trade effects being small and foreign countries free of financial frictions, they will not experience any welfare change. For the home economy, Proposition 3 applies. Being financially constrained, it benefits from a strictly positive welfare gain since the policy boosts investment with an above normal rate of return. Since the home country gains while no foreign economy looses in this scenario, world welfare rises.

5.2 R&D Subsidies

Instead of protection, the home economy could subsidize R&D to become more competitive in the innovative industry. Intuition is that an R&D subsidy targets finance constraints more directly than protection. In expanding the innovative sector, it drives down the world price, leading to terms of trade effects on foreign economies that are favorable or unfavorable depending on their trade balance. A lower world price, however, tightens finance constraints in all foreign economies and thereby reduces their welfare. The price erosion also feeds back negatively on domestic equilibrium, irrespective of whether the country is a net exporter or importer, and reduces the possible welfare gains. Given (25) and the results of section 3, we can state:

Proposition 9 ***(R&D subsidy in a large country)*** *(a) An R&D subsidy boosts aggregate supply, reduces the world price of innovative goods, and leads to a negative feedback effect on the domestic economy. Investment of unconstrained firms falls. Compared to a small open economy, the increase in constrained firm investment, innovation, aggregate supply and welfare are smaller. (b) The reduction in the world price reduces firm level investments, innovation and trade surpluses in foreign economies. Welfare in foreign export nations strongly falls due to a tightening of finance constraints and a deterioration of terms of trade while welfare changes in foreign import nations are ambiguous.*

It is unlikely that the negative feedback effect could overturn the direct effects of an R&D subsidy as they obtain in a small open economy. Obviously, the smaller the share ω of the home economy in world GDP is, the smaller is the impact on the world price v^*, and the smaller are the negative feedback effects. The feedback effect from a declining output price is strongest in the closed economy. If we can show the welfare gain to be positive in a closed country, it will a fortiori be positive in an open economy since the negative feedback is weaker. In Appendix A, we give a condition such that the qualitative results of the small open economy continue to hold in a closed economy. The condition is that the supply effect from induced innovation is not too strong, i.e. not too many firms switch from standard, low volume producers to innovative, high volume prodrurcers.

5.3 Financial Development

More effective monitoring and better oversight of firms boosts the debt capacity of innovative firms which face the greatest difficulty to access the capital market. Financial maturation thus triggers a supply side expansion and drives down the world price by

$\hat{v}^* = -(\omega\zeta_m/\zeta_v^*)\,\hat{m}$, see (25). The lower price reduces investment and output of unconstrained, standard firms and retards the expansion of constrained innovative companies. The beneficial effects are thus scaled down.

Proposition 10 ***(Financial development in a large country)*** *The reduction in the world price dampens the supply-side expansion in the home country. Investment and profits of unconstrained firms fall. Compared to a small open economy, the increase in constrained firm investment and profit is smaller, implying a smaller increase in innovation and welfare, and a smaller reduction of the trade deficit in innovative goods. (b) The reduction in the world price reduces firm level investments, innovation and trade surpluses in foreign economies. Welfare in foreign export nations strongly falls due to a tightening of finance constraints and a deterioration of terms of trade while welfare changes in foreign import nations are ambiguous.*

In Appendix B, we give conditions such that the qualitative results of the small open economy continue to hold in a closed economy. So they must hold a fortiori in large open economies where the negative feedback effect is weaker.

6 Conclusions

To investigate the interaction between innovation, finance and trade, we have proposed a multi-country two sector model with capital and sector specific labor. A discrete R&D decision splits firms into innovative and standard ones. Standard firms are unconstrained and invest at a low scale until the rate of return is equal to the cost of capital. Given prior R&D spending, innovative firms are left with little own assets, are highly productive and could invest at a large scale in the subsequent expansion stage but are credit rationed. These assumptions reflect the stylized fact that it is mostly the more innovative and smaller firms, small in terms of little own assets, which have difficulty in raising external funds. With investment being restricted, innovative firms earn an above normal, excess return on capital and have unexploited investment opportunities. The credit constraint is partly relaxed by specialized intermediaries which actively monitor and supervise firms, thereby raise their debt capacity and allow them to profitably invest at a larger scale.

Using this framework, we have investigated the role of three alternative policy approaches which address financial frictions in distinct ways. Assuming We find that import protection, in raising the domestic price and earnings per firm, also boosts the debt capacity of constrained firms. Protection thereby relaxes finance constraints and allows innovative firms with an above normal return to invest at a larger scale. For this reason, a small level of protection can raise domestic welfare, provided that terms of trade effects in the importing country are small. The second policy is an R&D subsidy which boosts innovation and welfare, not because of knowledge spillovers which are excluded in our model, but because these subsidies strengthen the internal funds. Being left with larger own assets after R&D spending, innovating firms succeed to attract a larger amount of external funds, allowing them to more fully exploit profitable investment opportunities with an excess return. The policy again boosts national welfare and shifts comparative advantage towards the innovative sector.

Finally, we investigate the consequences of financial sector development which we interpret to mean that active banks become more productive in monitoring firms. The higher monitoring productivity again raises firms' debt capacity, relaxes finance constraints in the innovative sector and boosts national welfare. While all three policies reduce financial frictions and yield welfare gains at home, the consequences on foreign welfare are less clear and depend on the specific interaction of terms of trade effects and financial frictions. The reduction in the world price strongly hurts foreign export nations, not only because of a negative terms of trade effect, but also because a lower price tightens finance constraints. Welfare in foreign import countries changes ambiguously since terms of trade and financial frictions work in opposite ways.

Appendix

A. R&D Subsidy in a Closed Economy In autarky, where $\eta = \eta_s$, an R&D subsidy reduces the equilibrium output price by $\hat{v} = -(\zeta_\sigma/\zeta_v) \cdot \hat{\sigma}$. Plugging into (24) yields $\hat{U} = \rho\eta_i\eta_s [(\varepsilon + \phi_v)\hat{v} + \phi_\sigma\hat{\sigma}]$ or

$$\hat{U} = \rho \cdot \eta_i\eta\Omega_\sigma/\zeta_v \cdot \hat{\sigma}, \quad \Omega_\sigma \equiv \phi_\sigma\zeta_v - (\varepsilon + \phi_v)\zeta_\sigma. \tag{A.1}$$

Clearly, there is an ambiguous welfare effect that stems from the negative consequences of the falling output price on the finance constraint. Evaluating the coefficient, we find

$$\begin{aligned} \Omega_\sigma &\equiv \phi_\sigma \left[(1-\eta) + \alpha\varepsilon\frac{s_u x_u}{\bar{x}}\right]\eta - \Gamma \cdot \frac{x_c - x_u}{\bar{x}} q^2 g(q)\eta, \\ \Gamma &\equiv (\varepsilon + \phi_v)\mu_\sigma - \mu_v\phi_\sigma = [(1-q)x_c + qx_u]\, pv/(\delta I_c) > 0, \end{aligned}$$

where the last equality uses $q = kR/(\pi_c - \pi_u)$. The subsidy boosts welfare if innovation and firm composition are exogenous or inelastic ($\mu_\sigma \to 0$, $\mu_v \to 0$ implying $\Gamma \to 0$ and $\Omega_\sigma > 0$). The coefficient Ω_σ is also positive if $\frac{x_c - x_u}{\bar{x}} q^2 g(q)$ is small, i.e. if the subsidy moves only a few firms from the unconstrained to the constrained regime.

The falling price also offsets the direct effect of the subsidy on constrained investment. Substituting the equilibrium price change into $\hat{I}_c = (\varepsilon + \phi_v) \cdot \hat{v} + \phi_\sigma \cdot \hat{\sigma}$ yields

$$\hat{I}_c = \Omega_\sigma/\zeta_v \cdot \hat{\sigma}, \tag{A.2}$$

where $\Omega_\sigma = \phi_\sigma\zeta_v - (\varepsilon + \phi_v)\zeta_\sigma$ is given above and is positive under the same conditions.

Finally, by (18), the extensive innovation margin in a closed economy changes by

$$\hat{q} = -\mu_v \cdot \hat{v} - \mu_\sigma \cdot \hat{\sigma} = -\frac{\Omega_q}{\zeta_v} \cdot \hat{\sigma}, \quad \Omega_q = \mu_\sigma\zeta_v - \mu_v\zeta_\sigma > 0. \tag{A.3}$$

In the first best, $\mu_\sigma \equiv 1$ and $\zeta_{x,v} \equiv \alpha\varepsilon + \frac{x_c - x_u}{\bar{x}} q^2 g(q)\mu_v$ and $\zeta_v \equiv (1-\eta_s)\eta + \alpha\varepsilon\eta_s + \frac{x_c - x_u}{\bar{x}} q^2 g(q)\mu_v\eta_s$ and $\zeta_\sigma = \frac{x_c - x_u}{\bar{x}} q^2 g(q)\eta_s$, giving $\Omega_q = (1-\eta_s)\eta + \alpha\varepsilon\eta_s > 0$. In general, we compute $\Omega_q = \mu_\sigma\zeta_v - \mu_v\zeta_\sigma$. Noting $\Gamma = (\varepsilon + \phi_v)\mu_\sigma - \mu_v\phi_\sigma$ from above, we have

$$\begin{aligned} \Omega_q &= \mu_\sigma \left[(1-\eta_s)\eta + \alpha\left(\varepsilon + \phi_v\frac{s_c x_c}{\bar{x}}\right)\eta_s\right] - \frac{s_c x_c \alpha}{\bar{x}}\eta_s\phi_\sigma\mu_v - \rho\eta\eta_i\eta_s \cdot \Gamma, \\ \Omega_q &= \mu_\sigma \left[(1-\eta_s)\eta + \alpha\varepsilon\frac{s_u x_u}{\bar{x}}\eta_s\right] + \Gamma \cdot \left(\frac{s_c x_c \alpha}{\bar{x}} - \rho\eta\eta_i\right)\eta_s > 0, \end{aligned}$$

where the second line follows upon expanding ϕ_v in the first square bracket to $\phi_v + \varepsilon - \varepsilon$. Since $\frac{s_c x_c \alpha}{\bar{x}} - \rho\eta\eta_i > 0$ as noted subsequent to (23), an innovation subsidy clearly boosts innovation in a closed economy as well.

B. Financial Development in a Closed Economy: In autarky, the price reduction is $\hat{v} = -(\zeta_m/\zeta_v)\,\hat{m}$. Plugging into (24) yields $\hat{U} = \rho\eta_i\eta\,[(\varepsilon + \phi_v)\,\hat{v} + \phi_m\hat{m}]$ or

$$\hat{U} = \rho \cdot \eta_i \eta \Omega_m/\zeta_v \cdot \hat{m} > 0, \quad \Omega_m \equiv \phi_m\zeta_v - (\varepsilon + \phi_v)\,\zeta_m > 0. \tag{B.1}$$

By rewriting the coefficient Ω_m, we can show it to be positive,

$$\begin{aligned} \Omega_m &= \phi_m \eta \left[(1-\eta) + \frac{s_u x_u}{\bar{x}}\alpha\varepsilon\right] + \Gamma_m \cdot \eta \frac{x_c - x_u}{\bar{x}} q^2 g\,(q) > 0, \\ \Gamma_m &\equiv \phi_m \mu_v - (\varepsilon + \phi_v)\,\mu_m = \frac{pv\,(x_c - x_u)}{\pi_c - \pi_u}\phi_m > 0. \end{aligned}$$

Clearly, financial development boosts welfare in a closed economy.

Constrained investment changes by $\hat{I}_c = (\varepsilon + \phi_v)\,\hat{v} + \phi_m\hat{m}$. Substituting the equilibrium price cut leaves a net positive investment stimulus in the closed economy,

$$\hat{I}_c = (\Omega_m/\zeta_v) \cdot \hat{m}. \tag{B.2}$$

The innovation threshold in (18) changes by $\hat{q} = -\mu_v\hat{v} - \mu_m\hat{m}$, which gives

$$\hat{q} = -\Omega/\zeta_v \cdot \hat{m}, \quad \Omega \equiv \mu_m\zeta_v - \mu_v\zeta_m. \tag{B.3}$$

To sign of Ω, note $\Gamma_m > 0$, expand ϕ_v to $\phi_v + \varepsilon - \varepsilon$, collect terms involving Γ_m, and use $\alpha = I_c x_c'/x_c$ as well as $\eta_i = s_c I_c/(vp\bar{x})$ and $\rho = p\,(vx_c' - i) - c^m$,

$$\Omega \equiv \mu_m \left[1 - \eta + \varepsilon \frac{s_u x_u}{\bar{x}} \alpha\right] \eta - \Gamma_m \cdot \left[\frac{s_c x_c}{\bar{x}}\alpha - \rho\eta\eta_i\right] \eta,$$

where the second square bracket $\frac{s_c x_c}{\bar{x}}\alpha - \rho\eta\eta_i$ is positive by the result noted after (23). So, in principle, financial development affects innovation in an ambiguous way since Γ_m is positive. In a large open economy, the feedback is scaled down, so that innovation must be encouraged if the economy's weight in the world economy is not too large.

References

[1] Aghion, Philippe, Thibault Fally and Stefano Scarpetta (2007), Credit Constraints as a Barrier to the Entry and Post-Entry Growth of Firms, *Economic Policy 22*, 731-779.

[2] Antras, Pol and Ricardo J. Caballero (2009), Trade and Capital Flows: A Financial Frictions Perspective, *Journal of Political Economy 117*, 701-744.

[3] Antras, Pol, Mihir A. Desai and Fritz C. Foley (2009), Multinational Firms, FDI Flows and Imperfect Capital Markets, *Quarterly Journal of Economics 124*, 1171-1219.

[4] Baldwin, Richard E. (1989), Exporting the Capital Markets: Comparative Advantage and Capital Market Imperfections, in: David B. Audretsch, Leo Sleuwaegen,and Hideki Yamawaki (eds.), *The Convergence of International and Domestic Markets*, Amsterdam: North Holland, 135-152.

[5] Beck, Thorsten (2002), Financial Development and International Trade: Is There A Link?, *Journal of International Economics* 57, 107-131.

[6] Beck, Thorsten (2003), Financial Dependence and International Trade, *Review of International Economics* 11, 296-316.

[7] Beck, Thorsten, Asli Demirgüc-Kunt, and Vojislav Maksimovic (2005), Financial and Legal Constraints to Growth: Does Firm Size Matter?, *Journal of Finance 60*, 137-177.

[8] Beck, Thorsten, Asli Demirgüc-Kunt, and Vojislav Maksimovic (2008), Financing Patterns Around the World: Are Small Firms Different?, *Journal of Financial Economics 89*, 467-487.

[9] Bloom, Nick, Rachel Griffith, and John Van Reenen (2002), Do R&D Tax Credits Work? Evidence from a Panel of Countries 1979-1997, *Journal of Public Economics 85*, 1-31.

[10] Brown, James R. and Bruce C. Petersen (2009), Why Has the Investment-Cash Flow Sensitivity Declined so Sharply? Rising R&D and Equity Market Developments, *Journal of Banking and Finance 33*, 971-984.

[11] Calomiris, Charles W. and R. Glenn Hubbard (1995), Internal Finance and Investment: Evidence from the Undistributed Profits Tax of 1936-37, *Journal of Business 68*, 443-482.

[12] Carpenter, Robert E. and Bruce C. Petersen (2002), Is the Growth of Small Firms Constrained by Internal Finance?, *Review of Economics and Statistics 84*, 298-309.

[13] Chirinko, Robert S. and Huntley Schaller (1995), Why Does Liquidity Matter in Investment Equations?, *Journal of Money, Credit and Banking 27*, 527-548.

[14] Chor, Davin, C. Fritz Foley, and Kalina Manova (2008), Host Country Financial Development and MNC Activity, unpublished manuscript, Harvard University.

[15] Do, Quy-Toan and Andrei A. Levchenko (2007), Comparative Advantage, Demand for External Finance, and Financial Development, *Journal of International Economics 86*, 796-834.

[16] Egger, Peter and Christian Keuschnigg (2010), *Corporate Finance and Comparative Advantage*, University of St. Gallen, www.alexandria.unisg.ch/Publikationen/51206.

[17] Fazzari, Steven M. and Bruce C. Petersen (1993), Working Capital and Fixed Investment: New Evidence on Financing Constraints, *Rand Journal of Economics 24*, 328-342.

[18] Fisman, Raymond and Inessa Love (2003), Trade Credit, Financial Intermediary Development, and Industry Growth, *Journal of Finance 58*, 353-374.

[19] Gorodnichenko, Yuriy and Monika Schnitzer (2010), *Financial Constraints and Innovation: Why Poor Countries Don't Catch Up*, CEPR DP 7721.

[20] Guiso, Luigi (1998), High-tech Firms and Credit Rationing, *Journal of Economic Behavior & Organization 35*, 39-59.

[21] Hall, Bronwyn H. (2002), The Financing of Research and Development, *Oxford Review of Economic Policy 18*, 35-51.

[22] Hall, Bronwyn H. and Josh Lerner (2009), The Financing of R&D and Innovation, NBER WP 15325; forthcoming in: Hall, B. H. and N. Rosenberg (eds.), *Handbook of the Economics of Innovation*. Amsterdam: North-Holland.

[23] Hall, Bronwyn H. and John Van Reenen (2000), How Effective are Fiscal Incentives for R&D? A Review of the Evidence, *Research Policy 29*, 449-469.

[24] Helpman, Elhanan, Marc J. Melitz, and Stephen R. Yeaple (2004), Export Versus FDI with Heterogeneous Firms, *American Economic Review 94*, 300-316.

[25] Himmelberg, Charles P. and Bruce C. Petersen (1994), R&D and Internal Finance: A Panel Study of Small Firms in High-tech Industries, *Review of Economics and Statistics 76*, 38-51.

[26] Holmstrom, Bengt and Jean Tirole (1997), Financial Intermediation, Loanable Funds, and the Real Sector, *Quarterly Journal of Economics 62*, 663-691.

[27] Hoshi, Takeo, Anil Kashyap, and David Scharfstein (1991), Corporate Structure, Liquidity, and Investment: Evidence from Japanese Industrial Groups, *Quarterly Journal of Economics 106*, 33-60.

[28] Hubbard, Glenn (1998), Capital Market Imperfections and Investment, *Journal of Economic Literature 36*, 193-225.

[29] Ju, Jiangdong and Shang-Jin Wei (2008), *When is Quality of Financial System a Source of Comparative Advantage?*, NBER WP 13984.

[30] Kaplan, Steven N. and Luigi Zingales (1997), Do Investment-Cash Flow Sensitivities Provide Useful Measures of Financing Constraints?, *Quarterly Journal of Economics 112*, 169-215.

[31] Keuschnigg, Christian and Evelyn Ribi (2010), *Profit Taxation, Innovation and the Financing of Heterogeneous Firms*, CEPR DP 7626 and University of St. Gallen, www.alexandria.unisg.ch/Publikationen/58583.

[32] Kletzer, Kenneth and Pranab Bardhan (1987), Credit Markets and Patterns of International Trade, *Journal of Development Economics* 27, 57-70.

[33] Manova, Kalina (2008a), Credit Constraints, Equity Market Liberalizations and International Trade, *Journal of International Economics* 76, 33-47.

[34] Manova, Kalina (2008b), *Credit Constraints, Heterogeneous Firms and International Trade*, NBER WP 14531.

[35] Matsuyama, Kiminori (2004), Financial Market Globalization, Symmetry-Breaking, and Endogenous Inequality of Nations, *Econometrica 72*, 853-884.

[36] Matsuyama, Kiminori (2005), Credit Market Imperfections and Patterns of International Trade and Capital Flows, *Journal of European Economic Association 3*, 714-723.

[37] Rajan, Raghuram G. and Luigi G. Zingales (1998), Financial Dependence and Growth, *American Economic Review* 88, 559-586.

[38] Schaller, Huntley (1993), Asymmetric Information, Liquidity Constraints, and Canadian Investment, *Canadian Journal of Economics 26*, 552-574.

[39] Svaleryd, Helena and Jonas Vlachos (2005), Financial Markets, the Pattern of Industrial Specialization and Comparative Advantage: Evidence from OECD Countries, *European Economic Review 49*, 113-144.

[40] Tirole, Jean (2006), *The Theory of Corporate Finance*, Princeton University Press.

[41] Tirole, Jean (2001), Corporate Governance, *Econometrica 69*, 1-35.

[42] Ughetto, Elisa (2008), Does Internal Finance Matter for R&D? New Evidence from a Panel of Italian Firms, *Cambridge Journal of Economics 32*, 907-925.

[43] Ughetto, Elisa (2009), Industrial Districts and Financial Constraints to Innovation, *International Review of Applied Economics 23*, 597-624.