Learning on the quick and cheap: microfoundations for the FDI productivity transmission mechanism

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Abstract

Gains from productivity and knowledge transmission arising from the presence of foreign firms has received a good deal of empirical attention, but theoretical micro-foundations for this mechanism are limited . Here I focus on production by foreign experts who may train domestic unskilled workers who work with them. Gains from training can in turn be decomposed into two types: (a) obtaining knowledge and skills at a *lower cost* than if they are self-learned at home, (b) producing domestic skilled workers *earlier in time* than if they the domestic economy had to rediscover the relevant knowledge through "reinventing the wheel". I develop a dynamic model in which the economy initially has very few skilled workers. Workers can withdraw from the labor force for two periods of self study and then produce as skilled workers in the third period. Alternatively, foreign experts can be hired in period 1 and domestic unskilled labor working with the experts become skilled in the second period. I analyze how production, training, and welfare depend on the cost of foreign experts in terms of the domestic export good. An extension to the issue of hold-up and rent sharing between skilled workers and firms without enforceable contracts is presented.

"I once asked a plumber who came to fix my water heater, and who did it in three minutes, how he dared to charge me eighty thousand lire for turning a little knob. He told me it had taken him twenty years to learn which knob to turn."

from "Wilful Behavior" , a novel by Donna Leon

"I wanted to work for a foreign company so I could learn from experts. My life would be much harder if I didn't have this job. Now we can think about the future. If I can afford it, I want to send my son to study overseas - maybe Australia or the United States."

Dang Thi Hai Yen, production manager at a Vietnamese factory sub-contracted by Nike, Inc.

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1. Introduction

There now exists a well-developed empirical literature on the transmission of technical/managerial knowledge and productivity "spillovers" between countries and whether trade or investment is a more important channel of transmission (for example: Keller 1998, 2002ab, Haskel and Slaughter 2002, Gong and Keller 2003, Javorcik 2004 and Javorcik and Spatareanu 2003).

In the latter vein of literature, several different ideas for the micro-foundations of the transmission mechanism have been proposed or modeled. Theoretical models have looked at linkages as a source of productivity spillover, so that upstream and/or downstream firms benefit from the arrival of multinationals (Markusen and Venables, 1999). This has generally been in the form of variety effects from supporting an increased number of intermediate or final goods. A second stream of theoretical analysis looks at workers or local firms learning from watching or working for foreign firms with a resulting increase in their productivity (Fosfuri, Motta, and Rønde 2001, Glass and Saggi 2002, Ethier and Markusen 1996, Markusen 2001). Empirical work in search of spillovers to local firms include Haddad and Harrison (1993), Blomström and Kokko (1998), Blomström and Sjöholm (1999), Aiken and Harrison and Lipsey (1996), Javorcik (2004), and Javorcik and Spatareanu (2003). Other empirical literature has documented that local firms and their managers often get their start as employees of multinational firms (Katz 1987, Hobday 1995, Hall and Khan 2003).

Very little in this literature is directed at modeling the precise micro-mechanism of how foreign skilled workers impart those skills to domestic workers. That then is the purpose of this paper. We focus on direct imports of the services of foreign experts as a method of both providing an important good or service and for training domestic workers faster and/or cheaper than they can learn on their own. I depart from the tradition of comparative steady-state analysis used in new growth theory, since I want to explicitly consider timing issues rather than merely steady-state levels and growth rates. For this reason, I use a very simple competitive constant-returns model with no spillovers, externalities, or other bells-and-whistles.

The economy lasts three periods, with a "dummy" fourth terminal period used to implement a finite time approximation to the steady state (Lau, Pahlke and Rutherford, 2002) . The economy initially has only a very small number of skilled workers who are needed to produce a non-traded good X. Unskilled workers can withdraw from production (of good Y) for two periods and learn to be skilled workers through a self-learning process ("reinventing the wheel) and become skilled workers in period three.

Instead of relying on learning by studying (LBS), the economy may import foreign experts as well as use existing domestic skilled workers who have accumulated expertise from previous activities. Foreign experts or domestic skilled workers can produce good X working alone in any period. Alternatively, foreign experts or domestic skilled workers can produce X in the first/second period and domestic unskilled labor working with them become skilled in the second/third period. I refer to this as learning by watching or working-with (LBW). In the latter event, in the second period these newly skilled domestic workers can produce X and can train additional domestic workers for period 3. As in the case of foreign experts, domestic skilled workers may also produce alone without training additional workers.

We solve for a perfect-foresight, competitive equilibrium, with the economy allowed to borrow subject to three-period trade balance constraint (I have worked out a period-by-period trade- balance constraint, but it yields rather obvious modifications so I have not included it here). There are fourteen possible training/production activities, and the set of activities operating in equilibrium is referred to as the regime.

An important parameter in the model is the cost of foreign experts in terms of the composite other good Y produced by the economy. When this cost is very high, domestic workers engage in LBS and few skilled workers and little X are available until period 3. At a somewhat lower cost, foreign experts are used in period one only and then more domestic skilled workers are trained in period 2 by the domestic workers trained by foreign experts in period 1. At a yet lower cost, all training is by foreign experts. Finally, at a very low cost, it doesn't pay to train hardly any one, and virtually all production in all periods is done by the foreigners working alone.

Gains from trade are a combination of: more X, getting X earlier, cheaper training of domestic workers, and getting domestic skilled workers earlier. X is available in period 1, and domestic skilled workers are available in period 2 instead of both of these things occurring first in period 3 when experts are very costly.

The base model has an implicit complete contracting assumption over the training and subsequent work of a skilled worker. The competitive equilibrium in which workers are trained by other workers typically has a solution in which the competitive firm earns negative returns in the first period followed by an excess of revenues over payments to skilled labor in subsequent periods. In line with recent interest in hold-up and rent sharing (Fosfuri, Motta, and Rønde 2001, Glass and Saggi 2002, Antrás 2002, 2003, Markusen 2001), I present an extension in which contracts cannot be enforced and so there is bilateral hold-up between firms and the newly trained workers. This lack of contract enforcement shifts the equilibrium away from LBW and towards less efficient LBS, slowing down the development of the economy.

The model and these results may be interesting in several empirical and policy contexts. From an empirical point of view, it may help interpret a number of findings including the fact that managers of local firms in developing countries often get their start working for multinationals. From a policy point of view, it suggests that foreigners are not substitutes for local skilled labor unless the former are very cheap, and that barriers to foreign firms and workers (e.g., visa, residence restrictions) and well as lack of contract enforcement may be costly.

2. The three-period model

(a) There are three time periods, t = 1,2,3. A fourth, terminal "period" used to approximate the steady state at the end of three period is used and discussed below.

(b) There are two goods, X and Y; both sectors competitive, constant returns to scale

(c) There are four factors of production, R, L, F, and S

(d) Y is produced from a sector-specific factor R, and unskilled labor L.

(e) X is produced from imported experts F and/or domestic skilled labor S and is non-traded.

(f) The stock of R and the initial stock of L are fixed. Initially there is a very small number of S.

Let subscript t denote time period. Y_t is produced from R_t , and L_t :

(1) $$Y_t = Y(R_t, L_{yt})$$

The role of R is to add convexity to the model: unskilled workers going to train must be drawn from the Y sector at increasing cost in terms of Y.

Let L_t denote the *stock* of unskilled workers at t, and let L_{st} give the unskilled workers entering training at t. There is one equation for the intra-period allocation of the unskilled worker stock and a second equation for the inter-period change in that stock.

(2) $L_t = L_{yt} + L_{st}$

(3) $L_{t+1} = L_t - L_{st}$

Let S_t denote the *stock* of skilled workers at t, and let NS_t denote the newly skilled at t. Skilled workers are produced from unskilled workers L. There are two ways skilled workers can be produced. First, an unskilled worker can go off and study for two period on his/her own and become skilled. Thus unskilled workers who withdraw from the labor force at t = 1 or 2, are skilled at t = 3 or t = 4 respectively.

(4) $NS_{t+2} = L_{st}$ Self-learning activity

The second is to work with existing skilled workers. An unskilled worker who works alongside a skilled worker in producing X becomes skilled in one time period rather than two. LBW is more time efficient than LBS.

When permitted, foreign skilled workers, called foreign experts (or just experts), can also be hired from abroad and paid for at a fixed rental price in terms of Y. When the economy is open, foreign experts can be hired at t = 1,2,3. They can produce X working alone (as can domestic skilled workers) or a domestic unskilled worker can work along side the expert (or domestic skilled worker) and become skilled in one period. Thus trade offers both X consumption earlier at t = 1 and allows domestic skilled workers to be produced more cheaply and earlier at t = 2. Both are available in significant numbers only at t = 3 in autarky.

(5) $X_t = F_t$ $\quad X_t = S_t$ Production only activities

(6) $\max[X_t, NS_{t+1}] = \min[F_t, L_{st}]$ Production/training activities (foreigners)

(7) $\max[X_t, NS_{t+1}] = \min[S_t, L_{st}]$ Production/training activities (domestic)

We assume no skills depreciation and so the equation of motion for S is

(8) $S_{t+1} = S_t + NS_{t+1}$

There are fourteen activities relating to X and/or training over the three period (several activities may be active at the same time). Codes to denote X production and/or training activity are give by a three-digit index: IJT.

I = D, F D denotes a domestic activity using no foreign experts,
F is an activity involving foreign experts

J = S, T, N S denotes self training, T training by existing skilled workers,
N denotes an activity without no training

T = 1,2,3 Time period (t = 4 has a special interpretation discussed below)

All activities involve production of X *except* DS1 and DS2, where domestic workers begin self-study for two period, and produce no X until t = 3 or t = 4. There are no activities FS1 or FS2 by definition (S is self-study by domestic workers).

At t = 1:

(A) domestic unskilled workers study alone, *no production* DS1

(B) domestic skilled workers work with unskilled domestics DT1
who become skilled at t = 2.

(C)	domestic skilled workers working alone	DN1
(D)	foreign experts working with unskilled domestics who become skilled at t = 2.	FT1
(E)	foreign experts working alone	FN1

At t = 2:

(A)	domestic unskilled workers study alone, *no production*	DS2
(B)	domestic skilled workers working with unskilled domestics who become skilled at t = 3.	DT2
(C)	domestic skilled workers working alone[1]	DN2
(D)	foreign experts working with unskilled domestics who become skilled at t = 3.	FT2
(E)	foreign experts working alone	FN2

At t = 3.

(A)	domestic skilled workers working with unskilled domestics who become skilled at t = 4.	DT3
(B)	domestic skilled workers working alone	DN3
(C)	foreign experts working with unskilled domestics who become skilled at t = 4.	FT3
(D)	foreign experts working alone	FN3

There is an intertemporal discount rate for the representative consumer assumed equal to an international borrowing/lending rate. When hiring foreigners is permitted, Y produced in any period can be exchanged for consultants in any period at a fixed price discounted by the time difference. This gives an intertemporal budget constrained allowing borrowing in early periods.

Notation is as follows, where prices are measured in terms of Y_1 (present value prices):

Y_i , p_{yi} quantity and price of good Y at time t = i

R_i , p_{ri} quantity and price of Y-sector-specific factor R at time t = i

[1]Note that DT2 and DN2 can only be positive if FT1 and/or DT1 is positive.

L_i , p_{li} quantity and asset price (not rental price) of unskilled labor L at time t = i[2]

U_i , p_{ui} quantity and (rental) price of unskilled labor U at time t = i

S_i , p_{si} quantity and (rental) price of skilled labor S at time t = i (S_1 is an endowment)

F_i , p_{fi} quantity and price of foreign experts F at time t = i

E_i , p_e quantity of "foreign exchange" at time t = i, price of foreign exchange at t = 1.

X_i , p_{xi} quantity and price of good X at time t = i

Factors R_i and L_1 are fixed quantities. L_2 and L_3 are variables, since labor available for unskilled work is reduced by the number of workers entering training. E is an artificial good: Y can be exchanged (exported) for E and E can then be exchanged for imported foreign experts F. With borrowing and lending allowed, E carries no subscript and thus exports of Y in any period can be exchanged for foreign experts in any period (zero interest rate). With no borrowing or lending, Y_i is exchanged for E_i which is exchanged for F_i.

A key parameter in the model is *cost*, which is the number of units of Y that must be exchanged for one for expert. Higher levels of *cost* are bad and *cost* will impact primarily on the substitution between LBS and LBW.

Convexity in the model comes from the fixed factor R in the Y sector, which is assumed Cobb-Douglas in the simulations: labor is drawn into training and X production at increasing cost in terms of Y, with $c_{yi}(p_{ui}, p_{ri})$ denoting the unit cost function for Y_i. In the X sector, units are chosen such that one domestic or foreign skilled worker produces one unit of X and, when training is involved, one unskilled worker works with one skilled worker (fixed coefficients) and that unskilled worker becomes one skilled worker for all future time periods (no skills

[2]Analogous to the price of a unit of capital, p_{li} is the present value at t = i of a unit of unskilled labor. p_{ui}, following line, is the single period rental price of unskilled labor at t = i.

depreciation).

Utility or welfare is treated as a produced good. The flow of utility in period i and the price of obtaining a unit of utility is

W_i , p_{wi} quantity and price of welfare at t = i

W, p_w quantity and price of intertemporal utility

The price of utility in period i and overall are given by standard cost or unit expenditure functions, denoted $c_{wi}(p_{yi}, p_{xi})$ and $c_w(p_{w1}, p_{w2}, p_{w3}, p_h)$ respectively, where p_h is the price of the terminal good, discussed shorty. A CES with an elasticity of substitution greater than one is assumed in these functions to ensure a solution with $X_1 = X_2 = 0$ in autarky (a value of 3 is used in the simulations within and between periods).

3. Closure: Approximation to an Infinite-Horizon Model

This model can be solved as a finite-horizon problem and indeed that is how I originally wrote the paper. However, there is a well-defined steady state in this model, and treating it as a three-period finite-horizon problem means that economies with different values of cost are in quite different positions relative to their steady state at the end of three periods. This makes comparisons hard to interpret.

An alternative is to use a methodology introduced bay Lau, Pahlke and Rutherford (2002) which treats a finite horizon model as an approximation to the true infinite-horizon problem. In our model here, there is a stationary, steady-state equilibrium, with all variables constant in levels once it is reached. AlthoughI have assumed that skilled labor is non-depreciating, a skilled laborer is produced by withdrawing one worker permanently out of the unskilled labor pool. The economy will asymptotically reach an outcome in which the present value of wages for an unskilled worker equal those from moving into training for one period and then producing as a skilled worker.

Let p_s and p_u denote the constant steady-state values of wages for skilled and unskilled workers and p_x the price of X and denote the current period t = 0. ρ is the discount and international borrowing rate. In the steady state, the production/training activity and the production only activity both yield zero profits. Let prices be in nominal rather than in present-value units. Over an infinite horizon, zero-profits implies that

$$(9) \qquad p_x + \sum_{i=1}^{\infty} (1+\rho)^{-i} p_s = \sum_{i=0}^{\infty} (1+\rho)^{-i} p_u + p_s \qquad p_x = p_s$$

$$(10) \qquad \sum_{i=1}^{\infty} (1+\rho)^{-i} p_s = \sum_{i=0}^{\infty} (1+\rho)^{-i} p_u \qquad p_x/\rho = p_u + p_u/\rho \qquad p_s = (1+\rho) p_u$$

In the steady state, the skilled wage exceeds the unskilled wage by the interest/discount rate ρ.

Our model could be treated as simply a finite horizon model of a few periods. However, this will give someone misleading results since economies facing higher costs for foreigners could be much further from the steady state after a couple of time period than those facing lower costs as noted above. What might be more relevant is to compare their transition paths over the over a few periods when they are both converging on the steady state.

Lau, Pahlke, and Rutherford (2002) develop a technique for approximating the infinite-horizon model in a finite number of periods, and I will adopt a variation of that technique here. This is to (a) introduce a terminal period, (b) introduce an additional dummy agent, and (c) introduce an additional artificial good. I will call the latter "heaven" (H). The dummy agent is endowed with heaven, but wants to sell this and "consume" terminal-period skilled labor. The fact that the final period skilled labor has no value after production in a finite horizon model is then eliminated by the representative agent selling its endowment to the dummy agent in exchange for heaven. The final element (d) is to introduce a tax or subsidy on the consumer's purchase of heaven with the tax rate adjusted endogenously until the terminal value of the skilled wage is related to the unskilled wage by equation (xx). This "forces" the economy into the steady state at the end of the fixed-horizon model.

Thus I introduce a fourth "period", in which no production takes place. The representative agent sells its endowment of skilled labor after period 3 (including any workers trained during period 3) to the dummy agent in exchange for heaven, with the tax/subsidy endogenously adjusted so that the price of skilled and unskilled labor are related by $p_s = (1 + \rho)p_u$. This ensures that the different economies we are comparing are not in different positions relative to a steady state at the end of period 3, making their transition paths more comparable.

The general-equilibrium model is a non-linear complementarity problem in mathematical programming language: a set of inequalities each with an associated non-negative variable. If an inequality holds as an equation the complementary variable is generally positive, and the complementary variable is zero if the associated inequality holds as a strict inequality in equilibrium.

There are three classes of inequalities in the model. First, there is a zero-profit inequality for each activity: unit cost must be greater than or equal to the price of the complementary good or factor. The complementary variables are activity levels, include production/training activities, labor supply activities, and trading activities. Second, there is a set of market clearing conditions for each good/factor, with prices as complementary variables. Third, there is an income balance or trade balance condition for the economy. For completeness, I present the entire list of inequalities and complementary variables in the next section. This can probably be skipped by readers interested in going to the simulation results in sections 4 and 5.

4. The full model: inequalities and unknowns (may be skipped)

Some additional notation is as follows. I is the income of the representative consumer and ID is the income of the dummy agent. The latter is endowed with heaven, H, which is valued only by the representative consumer, whereas the representative consumer carries skilled labor S_4 into the terminal period which is only valued by the dummy agent. Commodity and factor demands are found by the application of Shepard's lemma to cost and expenditure functions.

Zero-profit Inequality	Complementary variable	Description
$c_{yi}(p_{ui}, p_{ri}) \;\geq\; p_{yi}$	Y_i	Production activity Y_i
$p_{li} \;\geq\; p_{li+1} + p_{ui}$	U_i	Unskilled labor supply to Y_i [3]
$p_{l1} \;\geq\; p_{s3}$	*DS1*	S_3 produced from activity *DS1*
$p_{l1} + p_{s1} \;\geq\; p_{s2} + p_{s3} + p_{s4} + p_{x1}$	*DT1*	$X_1 = S_2 = S_3$ from activity *DT1*
$p_{s1} \;\geq\; p_{x1}$	*DN1*	X_1 from activity *DN1*

[3] Activities U_i account for change in the unskilled labor stock as workers move into training and production. Activity U_1 has L_1 as the input and U_1 (used in Y_1) and L_2 as outputs. Activity U_2 has L_2 as the input and U_2 (used in Y_2) and L_3 as outputs.

$p_{l1} + p_{f1} \geq p_{s2} + p_{s3} + p_{s4} + p_{x1}$	*FT1*	$X_1 = S_2 = S_3$ from activity *FT1*
$p_{f1} \geq p_{x1}$	*FN1*	X_1 from activity *FN2*
$p_{l2} \geq p_{s4}$	*DS2*	S_4 produced from activity *DS2*
$p_{l2} + p_{s2} \geq p_{s3} + p_{s4} + p_{x2}$	*DT2*	$X_2 = S_3$ from activity *DS2*
$p_{s2} \geq p_{x2}$	*DN2*	X_2 from activity *DN2*
$p_{l2} + p_{f2} \geq p_{s3} + p_{x2}$	*FT2*	$X_2 = S_3$ from activity *FT2*
$p_{f2} \geq p_{x2}$	*FN2*	X_2 from activity *FN2*
$p_{l3} + p_{s3} \geq p_{s4} + p_{x3}$	*DT3*	$X_3 = S_4$ from activity *DT3*
$p_{s3} \geq p_{x3}$	*DN3*	X_3 from activity *DN3*
$p_{l3} + p_{f3} \geq p_{s4} + p_{x3}$	*FT3*	$X_3 = S_4$ from activity *FT3*
$p_{f3} \geq p_{x3}$	*FN3*	X_3 from activity *FN3*
$p_e * cost * (1 + \rho)^{i-1} \geq p_{fi}$	F_i	Imports of experts at t = i
$p_{yi} * (1 + \rho)^{1-i} \geq p_e$	EY_i	Exports of Y at t = i
$c_{wi}(p_{yi}, p_{xi}) \geq p_{wi}$	W_i	Sub-welfare at t = i
$c_w(p_{w1}, p_{w2}, p_{w3}) \geq p_w$	W	Total (present value) of welfare

The next set of inequalities are market clearing conditions for each of the goods, factors, and trade activities. The complementary variables are prices of these quantity variables. Inequalities are written as supply greater than or equal to demand, where a strictly greater-than relationship implies that the price is zero (a free good) in equilibrium. Demands for goods/factors exploit Shephard's lemma in activities Y_i and W_i where there is variable substitution among inputs.

Market-clearing inequality | Complementary variable | Description

$Y_i > \frac{\partial c_{ui}}{\partial p_{yi}} W_i$	p_{yi}	Supply - demand for Y_i
$U_i > \frac{\partial c_{yi}}{\partial p_{ui}} Y_i$	p_{ui}	Supply - demand for U_i
$R_i > \frac{\partial c_{yi}}{\partial p_{ri}} Y_i$	p_{ri}	Supply - demand for R_i
$L_1 \geq U_1 + FS1 + DS1$	p_{l1}	Supply - demand for L_1
$U_1 \geq U_2 + FS2 + DS2$	p_{l2}	Supply - demand for L_2
$U_3 \geq U_2$	p_{l3}	Supply - demand for L_3
$S_1 \geq DT1 + DN1$	p_{s1}	Supply - demand for S_1
$FS1 \geq DS2 + DN2$	p_{s2}	Supply - demand for S_2
$DS1 + FS1 + DS2 + FS2 \geq DN3$	p_{s3}	Supply - demand for S_3
$S_4 \geq ID/(p_{s4}(1+t))$	p_{s4}	Supply - demand for S_4
$F_1 \geq FS1 + FN1$	p_{f1}	Supply - demand for F_1
$F_2 \geq FS2 + FN2$	p_{f2}	Supply - demand for F_2
$F_3 \geq FN3$	p_{f3}	Supply - demand for F_3
$FS1 + FN1 \geq \frac{\partial c_{w1}}{\partial p_{x1}} W_1$	p_{x1}	Supply - demand fo X_1
$FS2 + FN2 + DS2 + DN2 \geq \frac{\partial c_{w2}}{\partial p_{x2}} W_2$	p_{x2}	Supply - demand for X_2
$FN3 + DN3 \geq \frac{\partial c_{w3}}{\partial p_{w3}} W_3$	p_{x3}	Supply - demand for X_3

$W_i \geq \frac{\partial c_w}{\partial p_{wi}} W$	p_{wi}	Supply - demand for W_i
$W \geq I/p_w$	p_w	Supply - demand for W
$H \geq \frac{\partial c_w}{\partial p_h} W$	p_h	Supply - demand for Heaven
$\sum EY_i(1 + \rho)^{-i+1} \geq \sum cost_i F_i(1 + \rho)^{-i+1}$	p_e	Supply - demand for foreign exch

Income balance equation	Complementary Variable	Description
$I = p_{l1}L_1 + \sum p_{ri}R_i + p_{s4}tS_4$	I	Income balance, rep consumer
$ID = p_h H$	ID	Income balance, dummy

Auxiliary equation	Complementary Variable	Description
$p_{s3} = (1 + \rho)p_{l3}$	t	Tax/subsidy on heaven

In all, the model then consists of 61 inequalities in 61 unknowns. One equation is redundant by Walras' Law, so the price of "foreign exchange", p_e is used as numeraire and the corresponding equation is dropped from the model. The model is coded in Rutherford's MPS/GE, a subsystem of GAMS and solve using the non-linear complementarity solver in GAMS.

5. Results: varying the cost of foreign experts

Our key parameter, *cost*, is the amount of Y that must be exchanged for one foreign expert, and we could think of a cross-section of countries that differ in this measure. *Cost* can be interpreted in several ways. First, it is simply a Ricardian measure of the sophistication of the economy (the “factor bundles” need in Y to secure a foreign expert vary by country) . Second, each country has in fact a different Y good, and these differ in their value to the rest of the world. For some economies, Y could be oil, and at the other end some economies may have only casava to offer. Third, the economies may have characteristics that make foreigners more or less willing to come (civil unrest, kidnaping, disease). Finally, the economies could be identical but have different levels of a non-revenue-raising barrier to foreigners (e.g, bureaucratic red tape).

Figures 1-6 consider different levels of *cost*, solving the general-equilibrium model for each level. There is a very small number of domestic skilled workers in period 1. Figure 1 gives qualitative information on the equilibrium regime for differing levels of *cost*. That is, each row of the Figure gives a the general-equilibrium solution to the model for the range of *cost* shown in the first column.

The first row of Figure 1 is autarky, *cost* so high that the economy uses no foreigners. In this case, the self-training activity (DS1) is the only one that operates (except for DT1 where a very small number of skilled workers each train another worker) and skilled workers and X are available only in large numbers at t = 3. At a somewhat lower, but still high, level of *cost*, activity FT1 becomes active, so foreign experts are used sparingly for only period only in the production/training activity (so this corresponds to (9)-(11) above). Significant numbers of newly-skilled domestic workers at t = 2 train more domestic workers at t= 2 (DT2) and t = 3

(DT3).

As we go to progressively lower levels of *cost*, self-training is not used, and then additional domestic training in period 2 stops: it is optimal to do all training at t = 1. Foreign workers begin to be used for production only, and when they get very cheap, there is nearly zero training and foreigners do much of the production: FN1, FN2, FN3 are all active.

In order to show quantitative results, I rotate Figure 1, showing the cost of foreign experts, the exogenous variable, on the horizontal axis of Figure 2-6. Each *column* of Figures 2-6 represents an independent general-equilibrium solution to the model. Moving to the right represents solution to successive runs of the model, *not* moving through *time*. On the left of the horizontal axis, *cost* is prohibitively high, while on the right-hand edge foreign experts are cheap. Thus moving left to right corresponds to moving from economies facing a very high cost of experts toward economies facing a low-cost situation (*cost* is a trade cost variable, not a tariff, so there is no income effect of tariff revenue, and its value is exogenous to the government).

Figure 2 shows the number of domestic workers who are skilled by period 4, dividing them into self trained, trained by foreign experts, and those trained by trained domestic workers. As the cost of foreign experts falls, we see that self training falls to zero by the end of regime 3 (vertical dotted lines separate regimes). Over regimes 2-4, foreign experts are used at t = 1 only, and all other training is by domestic skilled workers. Beginning in regime 5, not all workers foreign-trained at t = 1 train an addition worker and instead an increasing number produce without training (FN2). In regime 6, training of additional workers at t = 2 ceases entirely and domestic skilled workers begin to be used for production only. Regimes 7 continues the transition of foreigners into production only, and all training by domestic skilled workers ceases in regime 8.

A final outcome in which foreigners are so cheap that all training ceases. Skilled wages are driven down relative to the unskilled wage in periods 2 and 3 sufficiently that the zero-profit condition for FT1 becomes slack and that for FN1 holds with equality.

(11) $p_{l1} + p_{f1} > p_{s2} + p_{s3} + p_{x1} \qquad p_{f1} = p_{x1} \quad => \qquad \sum p_{ui} = p_{l1} > p_{s2} + p_{s3}$

In regimes 2 and 3, the number of skilled workers trained by domestic and foreign skilled workers both increase. In regimes 4 and 5 domestic training falls but, as we will see there is just a substitution of foreign training for domestic training and the number of domestic skilled worker-years continues to rise. Over a substantial range, the use of foreign experts and the training of domestic skilled workers are *complements* in producing skilled workers, but that they become *substitutes* as foreign experts become very cheap.

Figures 3 and 4 graph the total number of domestic workers who start training in periods 1,2,3 (Figure 3) and the numbers completing their training in periods 2,3,4 (Figure 4). The relationship is not straightforward since the self-learning activity takes two periods while training takes only one. While the curves in Figures 2 and 3 superficially appear the same, note that which curve following which path switches in the two diagrams. There is a general sense that cheaper foreign experts move the start of training *earlier in time* in Figure 3. But note the number starting at t = 1 is non-monotonic: at very high levels of *cost*, many start into self-training (DS1) in period 1, while at lower *cost* this activity is eliminated and many start into training at t = 1 working with a foreign export (FT1).

While there is some ambiguity to the statement that cheaper foreign experts move the *onset of training* earlier time, there is no ambiguity to the statement that cheaper foreign experts move the *completion of training* earlier in time as shown in Figure 4. Again, the difference is due to the importance of the two-period self-learning activity at high levels of *cost* which has an early onset but late completion. In Figure 4, most workers complete training at t = 3,4. Completion of training at t = 4 disappears first, and then so does training competed at t = 3. At low levels of *cost*, all training is completed for the steady state at the end of period 1.

Figures 5 and 6 complete the analysis. In Figure 5, I graph the total number of workers trained by t = 4 as a function of *cost*, and also the cumulative number of skilled-worker-years produced, weighing each skilled worker by the number of time periods that the worker is skilled. It is interesting to note in Figure 5 that *cost* has very little effect on the total number of skilled workers produced in the transition to the steady state. However, the use of foreign experts at t = 1 shifts the completion date of training earlier (Figure 4) and so the foreigners have a significant impact on the total number of skilled-worker-years relative to autarky and self training. Both curves in Figure 5 fall to zero when *cost* is very low, since foreigners are used for production only and not for training as indicated earlier.

Figure 6 completes the analysis by showing *X* consumption as a function of *cost*. Again, we see that the principal effect of *cost* is to allow an earlier consumption of *X*, rather than waiting until t = 3 when self-trained workers begin to produce *X*. Note that there are two regimes where X_3 actually falls slightly with a fall in *cost*, and all gains are taken in the form of increases in X_1 and X_2 . Perfect smoothing is achieved after the shift to regime 5, where additional training of workers at t = 2 ceases (DS2 becomes inactive). At this point and over all of regime 5, there is an equal number of skilled workers in all time periods (n experts and the small number of domestic skilled workers at t= 1 produce n domestic skilled workers for periods

2 and 3 using FT1 and DT1), and so an equal X output in all time periods.

6. Unenforceable Contracts, Hold-Up

The model implicitly has a contracting assumption in training/production activities, where workers and firms sign a binding contract. As defined earlier, p_{l1} denote the "asset" price of an unskilled worker in the first period; that is, the three-period unskilled wage. Suppose that FT1 is active in equilibrium, earning zero profits while FN1 (production only) is inactive in equilibrium, implying negative profits if it were operated. The dual of (6) gives us that the costs of FT1 (unskilled worker price plus expert's wage) equals revenue (second and third period unskilled wages plus the price of X), while the dual of (5) is unprofitable:

(12) $p_{l1} + p_{f1} = p_{s2} + p_{s3} + p_{s4} + p_{x1} \quad p_{f1} > p_{x1}$

Together, these imply that

(13) $p_{s2} + p_{s3} + p_{s4} - p_{l1} > 0$ positive rents from training, equals

(14) $p_{f1} - p_{x1} > 0$ excess of foreign expert's wage over value of X output

This can only be supported as an equilibrium if the competitive firms and workers can write binding contracts at t = 1 which pays the worker the three-period unskilled wage, or by some other institutional arrangement such as bonding. To interpret it slightly differently, the unskilled worker could make a payment for training that leaves him with his opportunity costs, and this payment (when positive) allows an otherwise unprofitable production activity to operate.[4]

[4]Economic historian Ann Carlos tells us that the consensus in the apprenticeship literature is that apprentices were a losing proposition in early years but that apprenticeship periods ran about two years after the master broke even, during which he recouped his loss. Often families paid masters to take their sons, and legal institutions were developed to enforce the contract and return runaways to their masters.

Now assume instead that such contracts cannot be written or enforced. This will subject the firm and the worker to hold up after the worker is trained: the worker will wish to try to capture some of the surplus in (14). Newly-skilled workers would like to bargain for the skilled wage while the firms would like to pay the unskilled wage, the latter being the assumption in Figures 1-6 and in (12)-(14) above. This hold-up problem has been treated a number of time before, including Fosfuri, Motta, and Rønde (2001), Antrás (2002, 2003) Glass and Saggi (2002), Ethier and Markusen (1996), Markusen (2001). I have tried many alternative formulations and assumptions, and they all generated qualitatively similar results. Since this issue is now relatively well understood, I will treat it here in a rather simple way that is tractable in general equilibrium, and show the quantitative effects of the hold-up problem via simulation. Following the lead of the Antrás papers, I assume that the surplus available is resolved by a Nash bargaining problem.

In particular, let us make two rather arbitrary assumptions (as opposed to other arbitrary assumptions), which lead to a simple and intuitive outcome. First, assume that unskilled workers entering training must be paid the unskilled wage. Second, assume that following training, a worker cannot leave and work for another firm (e.g., skills are firm specific) but rather can only return to the unskilled labor pool.

Let q_{si} denote the wage actually received by a skilled worker in period i, as opposed to the market wage p_{si}. Let R_i ("rent") be the lifetime earning of a skilled worker entering training at t = i, denoted e_i, minus the outside option of the unskilled wage for three periods. For a worker entering training at t = 1, we have:

(15) $$R_1 = e_1 - p_{l1}, \qquad e_1 = q_{s4} + q_{s3} + q_{s2} + p_{u1} \qquad p_{l1} = p_{u1} + p_{u2} + p_{u3}$$

If an agreement with the worker is reached, the firm will earn a benefit equal to the market value of skilled wage (marginal product) after the worker is trained minus the payments e_i to the worker. The firm's outside option is assumed to be zero if no agreement is reached. The return to the firm if an agreement is reached, minus the (zero) outside option is denote Π_i, with its value given by replacing p_{li} in (13) with e_i.[5]

(16) $$\Pi_1 = p_{s2} + p_{s3} + p_{s4} - e_1$$

Let α denote the Nash bargaining weight for the worker. The Nash solution is to maximize the product of R and Π with respect to e.

(17) $$\max\ w.r.t\ e_1 \quad \Pi_1 R_1 = (e_1 - p_{l1})^{\alpha} (p_{s4} + p_{s3} + p_{s2} - e_1)^{1-\alpha}$$

The first-order condition for (17) is given by:

(18) $$\alpha (e_1 - p_{l1})^{\alpha - 1} (p_{s4} + p_{s3} + p_{s2} - e_1)^{1-\alpha} - (1-\alpha)(e_1 - p_{l1})^{\alpha} (p_{s4} + p_{s3} + p_{s2} - e_1)^{-\alpha} = 0$$

This simplifies to:

(19) $$\alpha (p_{s4} + p_{s3} + p_{s2} - e_1) - (1-\alpha)(e_1 - p_{l1}) = 0 \qquad \text{or}$$

(20) $$R_1 = (e_1 - p_{l1}) = \alpha (p_{s4} + p_{s3} + p_{s2} - p_{l1})$$

The result in (20) has a simple interpretation (the workers get a share α of the total surplus), and it is easy to implement in general equilibrium. The term on the right-hand side

[5]In general equilibrium, adjustments in production and demand for unskilled workers in training will occur until this surplus is equal to the excess of the initial skilled worker's wage at t = 1over the value of X output at t = 1 (p_{f1} - p_{x1}), as indicated in (13) and (14).

would equal the "revenue" received by taxing the firm's output of each skilled worker and subsidizing the input of each unskilled worker in the (ad valorem) amount tax = α. Since this is a representative consumer model, the lump-sum gift of this revenue to the representative consumer then implements (20); that is, the revenue received equals the earning of the workers who go into training in excess of the three-period unskilled wage they receive from the firm.

Figures 7 and 8 simulate this formulation, holding constant cost at the intermediate value of 6.4: from Figures 1-6, the initial regime at $\alpha = 0$ is DS1, DT1, FT1, DT2 and DT3 active. I then raise the "tax" = α in steps from 0 to 0.70 on the horizontal axis of Figures 7 and 8. Figure 7 shows a fairly intuitive outcome. The increasing bargaining power of the workers leads to a substitution away from the production/training activities using either domestic or foreign skilled workers and toward the self-training activity and toward the production-only activities (not shown). Referring back to (11)-(13), the forced rent sharing makes the production/training activities less profitable than the self-training activities and production-only activities which are not subject to hold up. General-equilibrium substitutions re-establish equilibrium at a higher skilled wages relative to unskilled wages before the terminal period.

Figure 8 shows the effects on the timing of training. Because of our closure that forces the economies onto the steady state at t = 4, the total number of workers training at t = 4 is roughly constant (right-hand axis). But the hold-up and rent sharing induces a delay in training and development: skilled workers are produced later in time than without these problems.

7. Summary

We can now summarize the results of our three-period model.

(1) Importing foreign experts allows the economy to produce skilled workers *earlier* and at a *lower cost* than through learning from scratch: reinventing the wheel. This in turn allows earlier and large consumption of the good produced using skilled labor.

(2) A key parameter is *cost*, the amount of good Y that must be exchanged for a for expert. I offered several interpretations of this parameter that might prove useful in empirical analysis.

(3) As the cost of foreign experts falls from an initially prohibitive level, they are used sparingly for one period only, with the newly-skilled domestic workers training additional domestic workers in period 2. As foreign experts become cheaper, virtually all training is done by foreigners, and when they are very cheap it does not pay to train anyone, and all production of X is done by the foreigners.

(4) As the cost of foreign experts falls from an initially prohibitive level, gains from trade are initially taken in the form of having skilled workers *earlier* rather than in having *more* skilled workers by t = 3, and in having X consumption *earlier* rather than (significantly) *more* X over three periods.

(5) Taken together, (2) and (3) imply that foreign experts and domestic skilled workers are *complements* up to the point where the former are very cheap. They are complements in the sense that a fall in the price of foreign experts induces the creation of domestic skilled workers earlier, and a large cumulative number of domestic skilled-worker years, although not necessarily a larger total of domestic skilled workers at t = 3. When foreigners are very cheap,

foreign experts and domestic skilled workers are *substitutes* in the sense that further falls in the cost of experts reduces and eventually eliminates domestic training.

(6) I concluded with a simple extension where contracts are not enforceable and thus firms are subject to holdup once they are trained (Fosfuri, Motta, and Rønde (2001), Antrás (2002, 2003) Glass and Saggi (2002), Ethier and Markusen (1996), Markusen (2001)). Newly skilled workers want to capture some of the surplus in earnings that they generate for the firm, but their alternative is to return to the unskilled labor pool (e.g., skills are firm specific) if an agreement cannot be reached. The Nash bargaining solution is used to resolve the problem as in Antrás. Results are intuitive: higher bargaining power for the worker leads, in general equilibrium, to a shift from LBW to the less efficient self-training. In the steady state, the number of workers trained is almost unaffected by hold-up, but they are trained later and hence the economy evolves more slowly without enforceable contracts.

References

Aitken, Brian, Ann Harrison, and Robert E. Lipsey (1996), “Wages and Foreign Ownership: A Comparative Study of Mexico, Venezuela, and the United States”, *Journal of International* Economics 40, 345-371.

Antràs, Pol. 2003. “Firms, Contracts, and Trade Structure”. *Quarterly Journal of Economics* 118: 1374-1418.

Antràs, Pol. 2005. “Incomplete Contracts and the Product Cycle”. *American Economic Review*, forthcoming.

Arnold, Jens Matthias and Beat Smarzynska Javorcik (2005), “Gifted kids or pushy parents: foreign acquisitions and plant performance in Indonesia”, World Bank working paper.

Blomstrom, Magnus, and Ari Kokko (1998), Foreign investment as a vehicle for international technology transfer, in: G.B. Navaretti, P. Dasgupta, K.-G. Maeler, and D. Siniscalco, eds., *Creation and Transfer of Knolwedge* , Springer-Verlag, Berlin, 279-311.

Blomström, Magnus and Fredrik Sjöholm (1999), “Technology transfer and spillovers: does local participation with multinationals matter?”, *European Economic Review* 43, 915-923.

Ethier, Wilfred J. and James R. Markusen (1996), Multinational firms, technology diffusion and trade, *Journal of International Economics* 41, 1-28.

Fosfuri, Andrea, Massimo Motta and Thomas Rønde (2001), Foreign direct investments and spillovers through workers' mobility, *Journal of International Economics* 53, 205-222.

Glass, Amy J. and Kamal Saggi (2002), “Multinational firms and technology transfer”, *Scandinavian Journal of Economics* 104, 495-5134.

Gong, G. And Wolfgang Keller (2003), “Convergence and polarization in global income levels: a review of recent results on the role of international technology diffusion”, *Research Policy* 32, 1055-1079.

Haddad, M, and A, Harrison (1993), Are there positive spillovers from Direct Foreign Investment: Evidence from Panel-Data for Morocco”, *Journal of Development Economics* 42, 51-74.

Hall, Bronwyn H., and Beethika Khan (2003), “Adoption of New Technology”, NBER working paper 9730, May.

Haskel, Jonathan E., Sonia C. Pereira, and Matthew J. Slaughter (2002), “Does Inward Foreign

Direct Investment Boost the Productivity of Domestic Firms?", NBER working paper 8724.

Hobday, Michael (1995), *Innovation in east asia: the challenge to japan* , Aldershot, London.

Javorcik, Beata Smarzynska (2004), "Does foreign direct investment increase the productivity of domestic firms? In search of spillovers through backward linkages", *American Economic Review* 93, 605-627.

Javorcik, Beata Smarzynska and Mariana Spatareanu (2003), "To share or not to share: does local participation matter for spillovers from foreign direct investment?", World Bank working paper 3118.

Katz, J.M. (1987), *Technology creation in latin american manufacturing industries,* St. Martin's Press, New York.

Keller, Wolfgang (1998), "Are international R&D spillovers trade-related? Analyzing spillovers among randomly matched trade partners", *European Economic Review* 42, 1469-1481.

Keller, Wolfgang (2002), "Geographic localization of international technology diffusion", *American Economic Review* 92, 120-142.

Keller, Wolfgang (2000), "Do trade patterns and technology flows affect productivity growth?", *World Bank Economic Review* 14, 17-47.

Lau Morten I, A. Pahlke and Thomas F. Rutherford (2002), "Approximating infinite-horizon models in a complementarity format: A primer in dynamic general equilibrium analysis", *Journal of Economic Dynamics and Control* 26, 577-609.

Markusen, James R. (2001), "Contracts, Intellectual Property Rights, and Multinational Investment in Developing Countries", *Journal of International Economics* 53, 189-204.

Markusen, James R. Anthony J. Venables (1999), "Foreign Direct Investment as a Catalyst for Industrial Development", *European Economic Review* 43, 335-356.

Markusen, James R., Thomas F. Rutherford and David Tarr (2005), "Trade and Foreign Direct Investment in Producer Services and the Market for Domestic Expertise", *Canadian Journal of Economics* 38, 758-777.

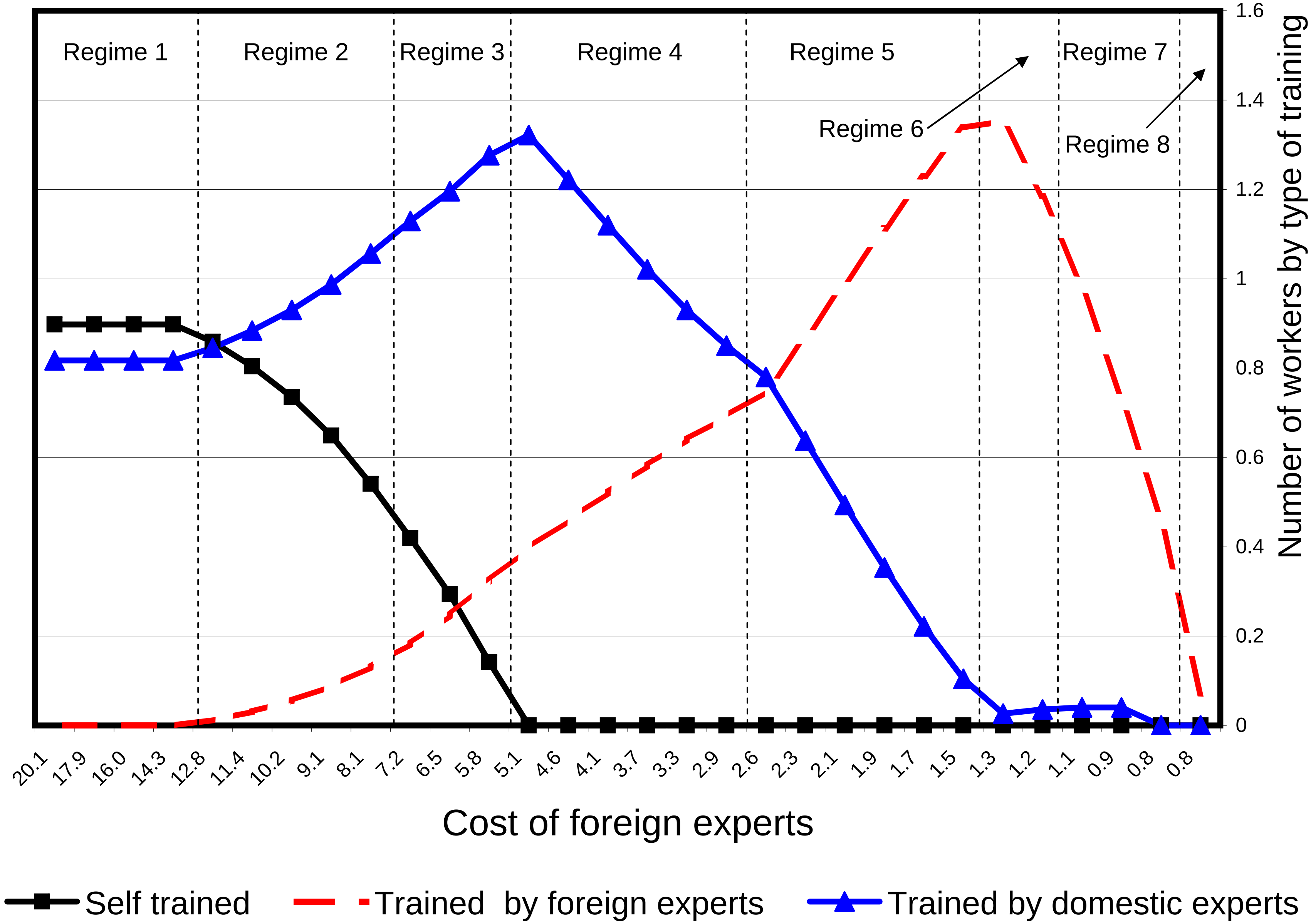
Figure 1: Production and training regimes - cost of foreign experts

COST OF FOREIGN EXPERTS	Period 1					Period 2					Period 3			
	DS1	DT1	DN1	FT1	FN1	DS2	DT2	DN2	FT2	FN2	DT3	DN3	FT3	FN3
20 - 14.3	*	*					*				*	*		
12.8 -8.1	*	*		*			*				*	*		
7.2 - 5.8	*	*		*			*				*			
5.1 - 2.9		*		*			*				*	*		
2.6 - 1.5		*		*			*	*		*		*		
1.3 - 1.2		*	*	*	*			*		*		*		*
1.1 - 1.0		*		*	*			*		*		*		*
0.8 - 0.7			*	*	*			*		*		*		*

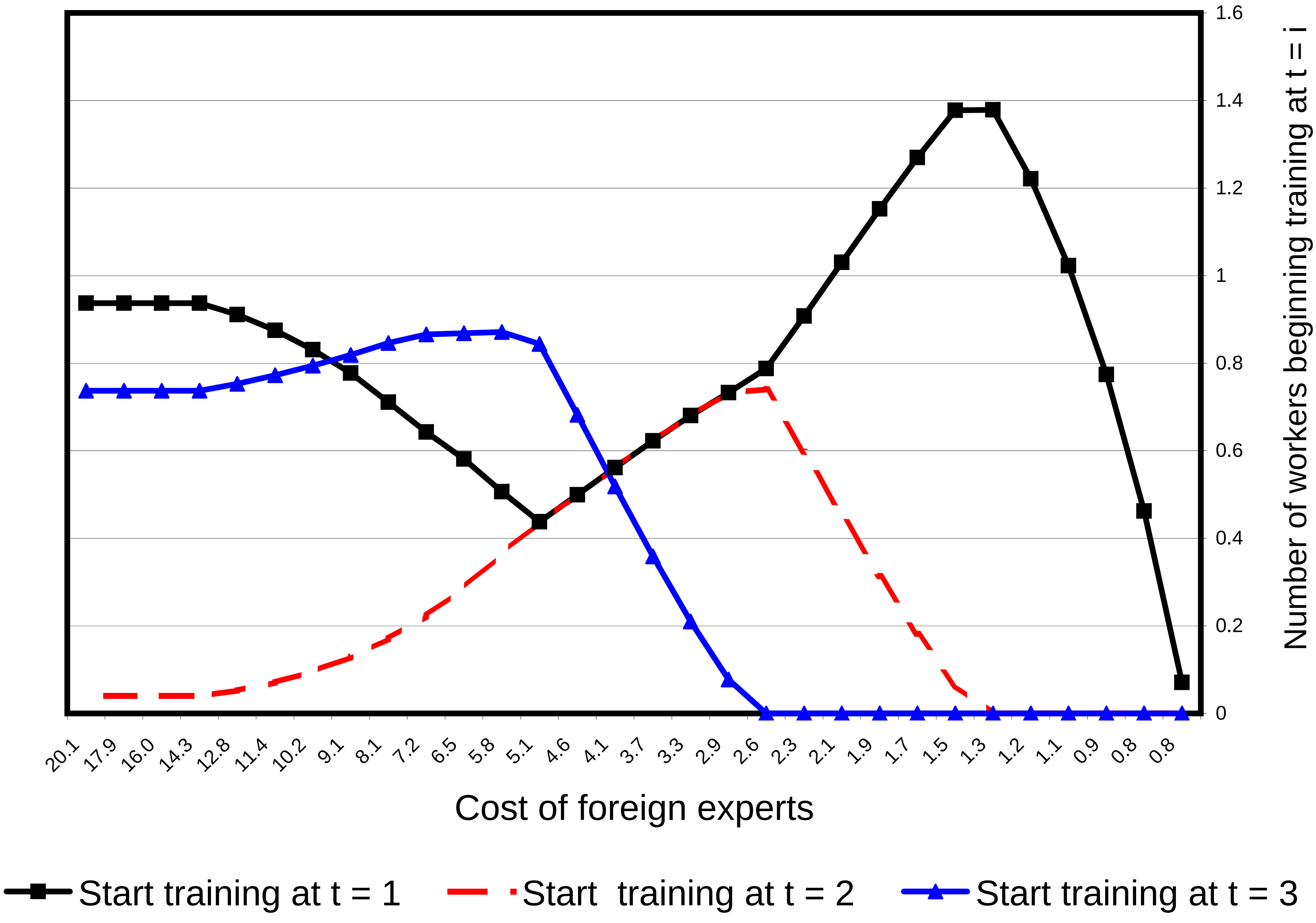
cost of foreign experts ↓

- self training, domestic training
- domestic and foreign training
- largely foreign training
- largely foreign experts for production only, no training

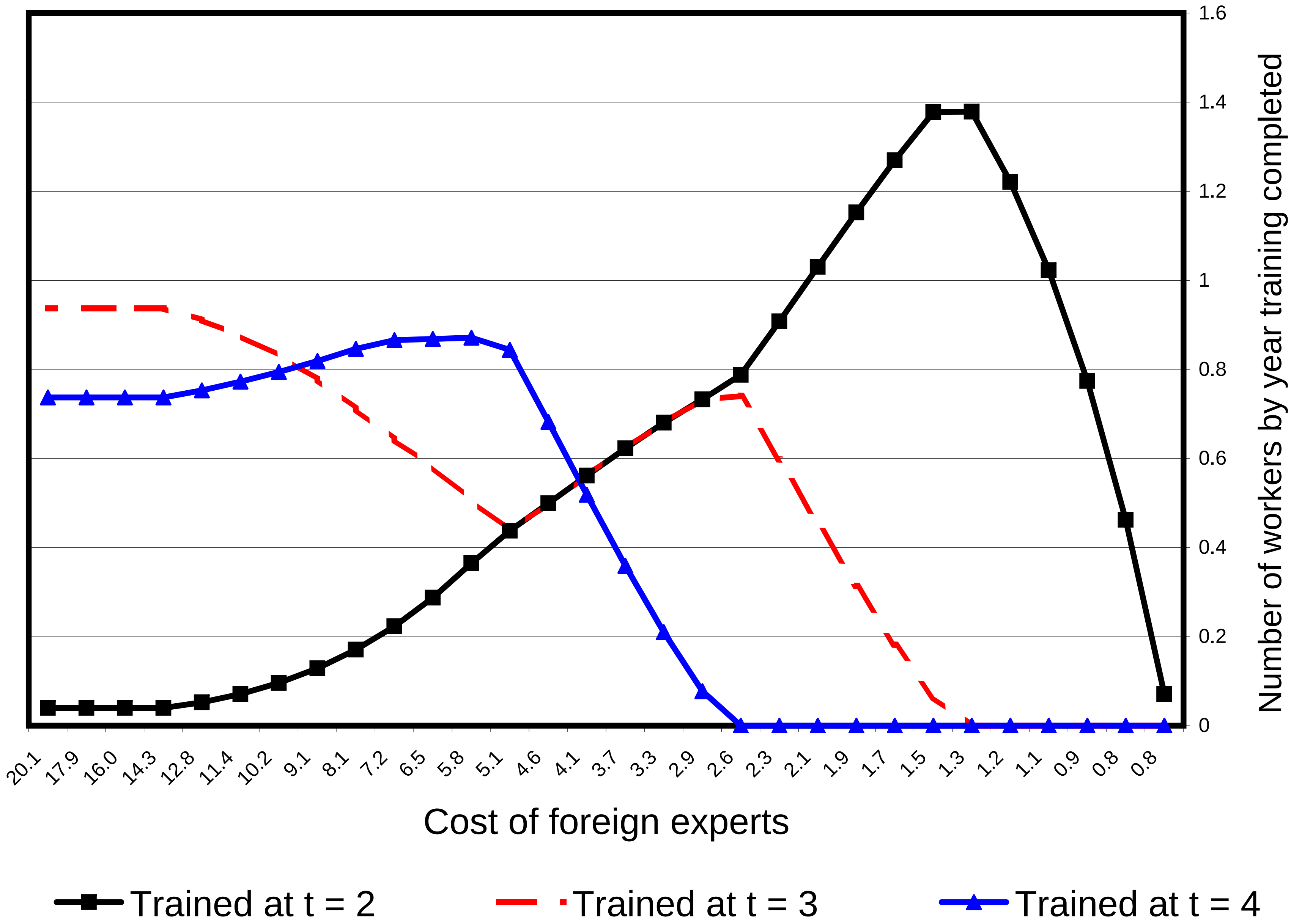
Figure 2: Total self/domestic trained and trained by foreign experts by t = 4



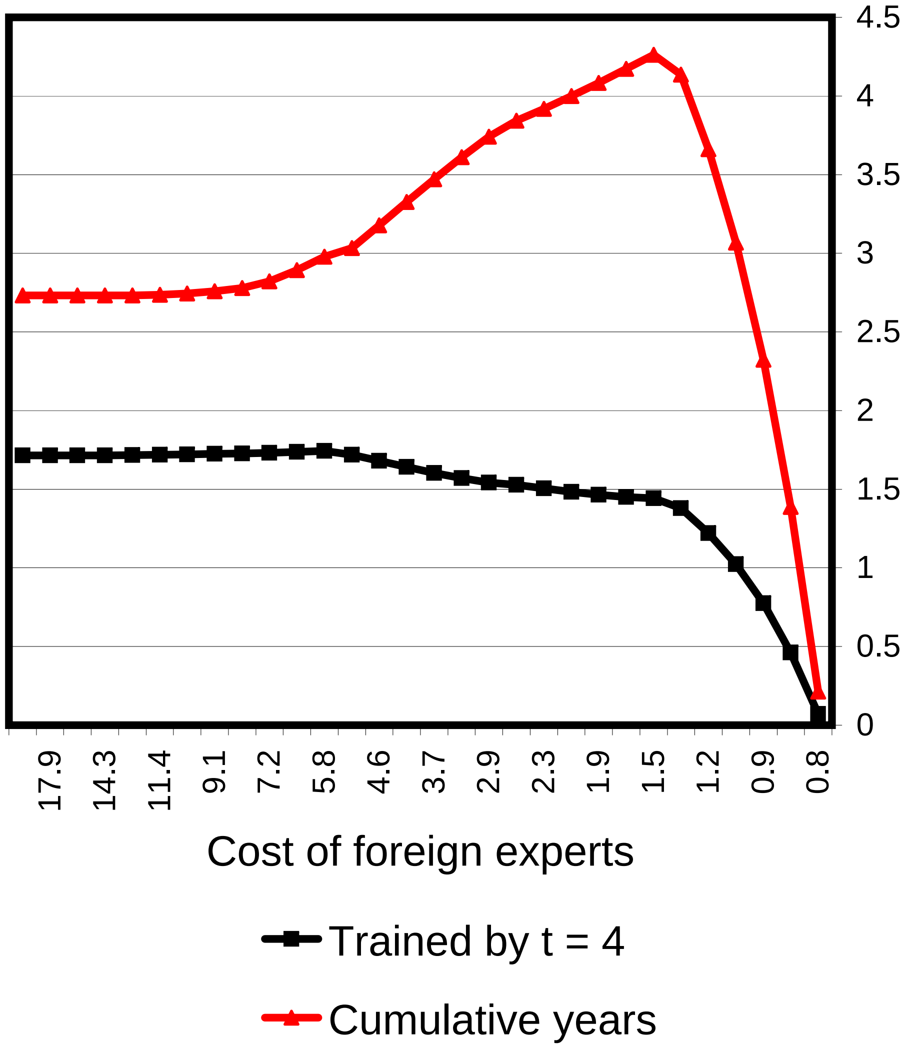
Figures 3: Timing of training: year training begins



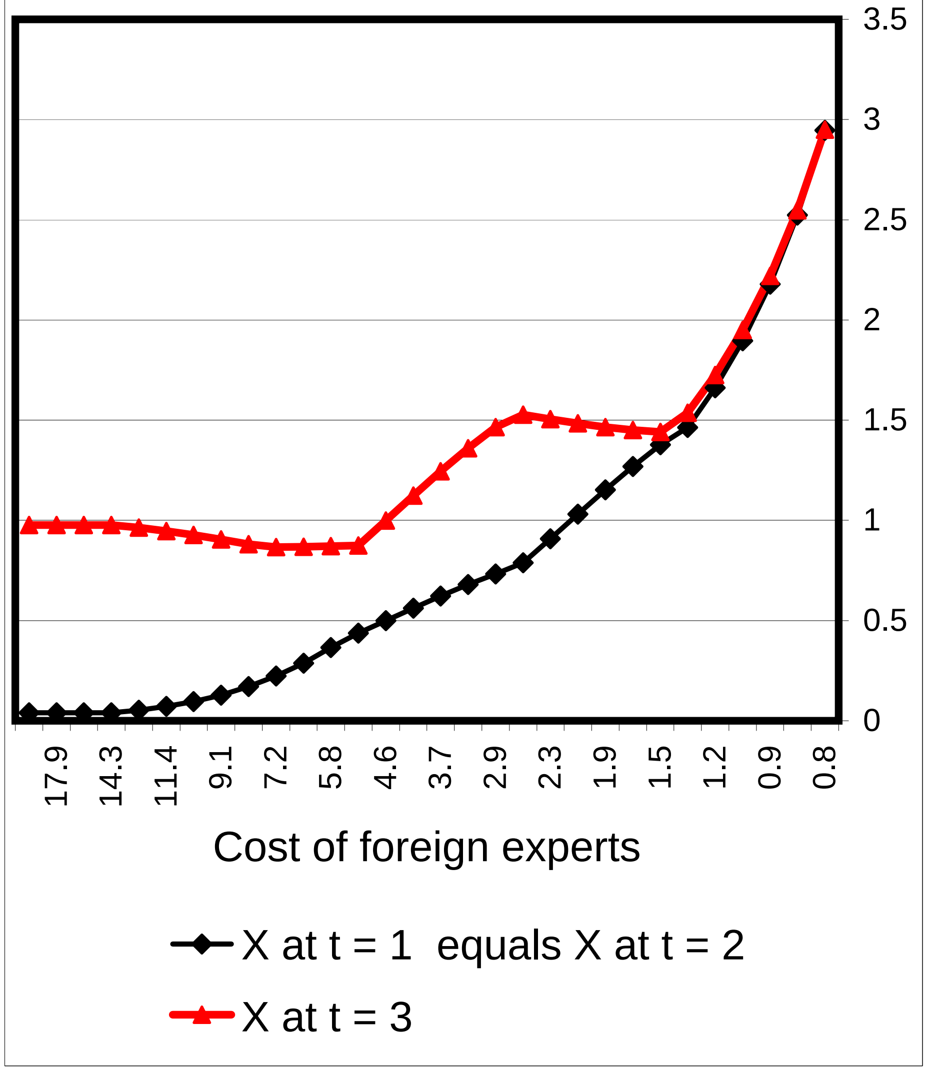
Figures 4: Timing of training: year training completed

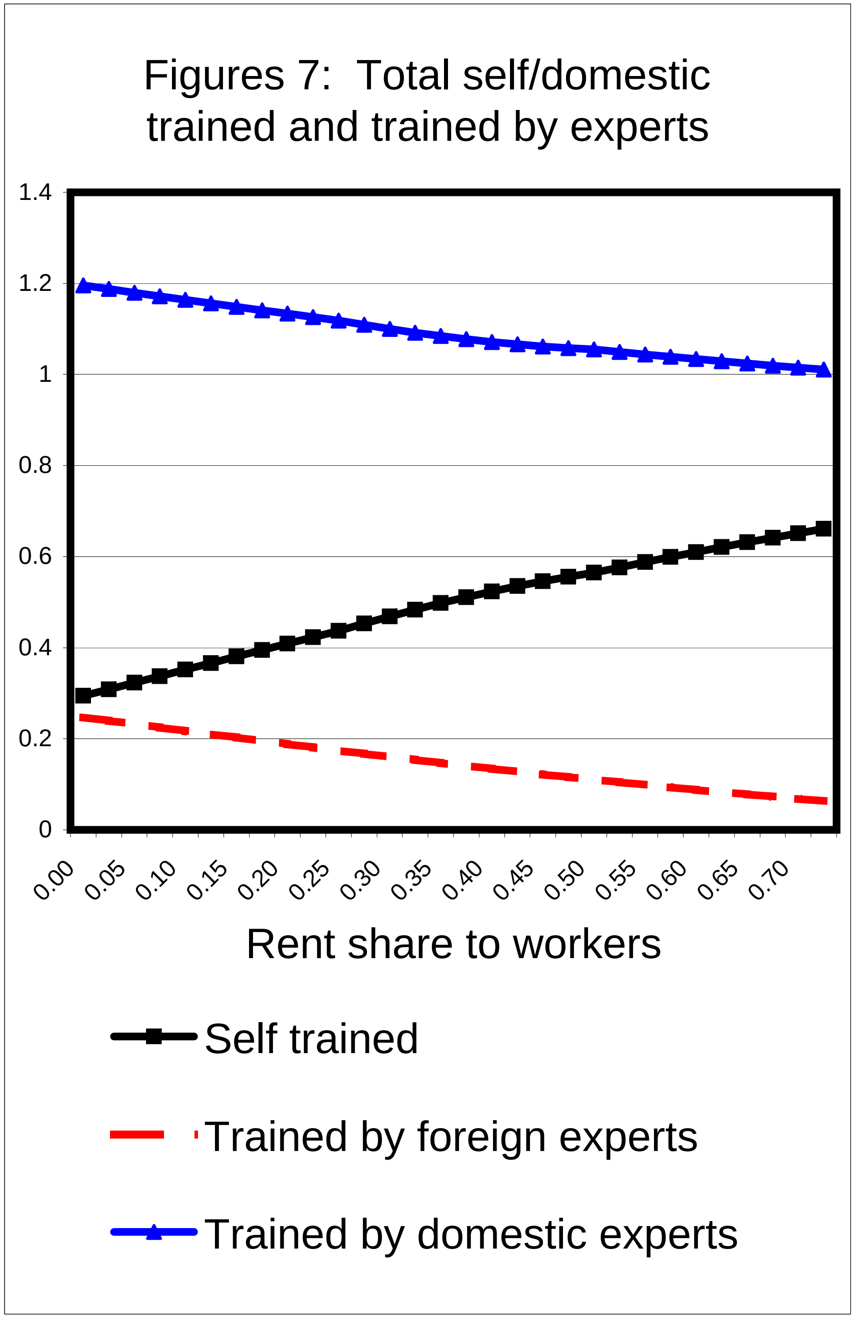


Figures 5: Total trained by t = 4 and total skilled-worker years

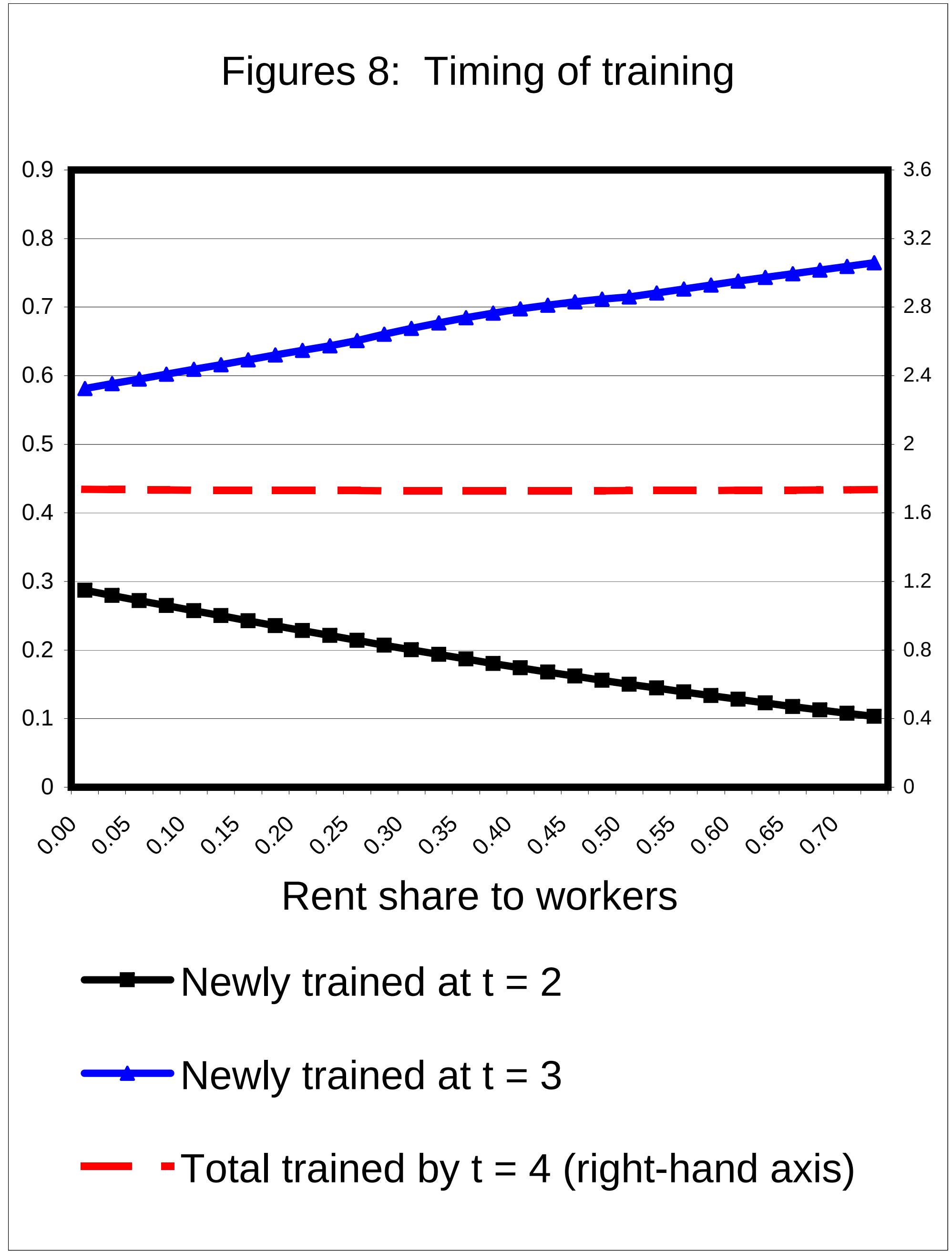


Figures 6: X production and consumption by period





Figures 7: Total self/domestic trained and trained by experts
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70
Rent share to workers
Self trained
Trained by foreign experts
Trained by domestic experts



Figures 8: Timing of training
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3.6
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70
Rent share to workers
Newly trained at t = 2
Newly trained at t = 3
Total trained by t = 4 (right-hand axis)