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Enrollment Responses to Labour Market Conditions: A Study of the Canadian Market for Scientists and Engineers

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Abstract

As Canada increasingly structures itself towards a "knowledge based economy", the supply of high-skilled professionals such as engineers and other science graduates acquires more importance. Following the theoretical framework developed by Ryoo and Rosen (2004), we develop and estimate a dynamic supply and demand model for engineers and scientists in Canada. We find that the estimated stock-flow dynamics are supportive of the theoretical model. The relative employment of engineers is quite sensitive to research and development (R&D) expenditures as a fraction of GDP, particularly after 1997. We then use the estimates to develop a dynamic impulse response function. Looking at the impact of a permanent increase in allocation towards R&D, we find that the adjustment process is relatively smooth and the market adjusts in about 2 to 8 years (plus the four years of natural lag in production) to within 80% of the final steady state. For a one-time improvement in R&D allocation, we find that under rational expectations, there is an initial increase in the number of science graduates, but then it falls to below the steady state value and remains there for a long period as the initial increase works its way through the market.

1 Introduction

In high-skill professions such as engineering, architecture etc., the primary source of supply is fresh graduates from post-secondary institutions. The supply response to changes in employment opportunities for such occupations thus depends crucially on potential students responding to these changes through their enrollment decisions into related disciplines. Whether or not the decisions are responsive, and if so, how long does it take for the "market to work" in high-skill occupations (which typically have long training periods) is a recurring theme in discussions about policies to promote growth. If this response is slow, or non-existent, innovation- (and growth-) promoting policies may be hampered by shortages of engineers and other high-skill professionals who are essential for the success of such policies. Thus, measurement of the magnitude and timing of this response in the market for high-skill professions is important for a better understanding of the appropriate policy prescription.

As Canada, along with some other OECD countries, increasingly structures itself towards a "knowledge based economy", the supply of high-skilled professionals such as engineers and other science graduates acquires even more importance. Not only are they crucial for implementing technological change but also in furthering the knowledge base. In this project, we seek to develop and estimate a dynamic supply and demand model for engineers and scientists in Canada. In doing so, our aim is to answer three main questions: (i) How important is the supply of fresh university graduates in determining the stock-flow dynamics in the Canadian science and engineering market? This lays down the significance of studying enrollment patterns as a crucial determinant for the number of scientists and engineers in Canada. (ii) What determines enrollment rates in Canadian science and engineering programs? How strongly do changes in earnings prospects affect these enrollment rates? (iii) How does enrollment adjust dynamically to changes in the market condition for scientists? How long does it take for the supply of fresh graduates to catch up with changes in demand?

While this type of dynamic supply demand analysis of occupational choice has a long history in economics, with the pioneering work of Freeman (1971, 1975 (physicists), 1976 (engineers)), Pashigian (1977), Pierce (1990), Ryoo and Rosen (2004), most of these studies have focussed on US labor markets. Among the most recent is work by Ryoo and Rosen (2004), who study the US engineering labor market. However, there has been little dynamic equilibrium study of the Canadian labor market as we do in this paper. A series of papers by Lavoie and Finnie (1997, 1998, 1999) make an in-depth analysis of engineering graduates in Canada, both in terms of earnings prospects and career dynamics. While they provide a comprehensive picture on the outcomes of engineering graduates in Canada, our paper is an attempt at equilibrium analysis of the science and engineering labor market by relating the supply (and demand) of engineers with the current stock and the resulting anticipated future earnings.

Consistent estimation of such a model will help understand how the supply of scientists and engineers responds (if at all) to such variables as public expenditure on R&D, infrastructure, and other factors that increase the demand for engineers. From a policy perspective, if this supply response is robust and rapid, then concerns that shortages of related high-skilled professionals can bog down growth-promoting policies maybe unfounded; on the other hand, if this supply response is slow, then additional policies to directly promote enrollment in related programs may be needed. An equilibrium analysis is particularly important here. For instance, if the government takes measures to increase directly the supply of skilled workers without paying a close attention to the demand side, the resulting imbalance in supply and demand may decrease the wage of skilled workers, thereby leading to overall downward enrollments in engineering.

In this paper, we combine data from the Survey of Consumer Finances and the Labour Force Survey to create a time-series on average yearly earnings of scientists and engineers in Canada and their stocks. Together with data on science and engineering degrees from the Centre for Education Statistics, we estimate a stock-flow dynamic relation, a demand equation and a supply equation for scientists in the Canadian market. What we find overall is that the estimated stock-flow dynamics are supportive of the theoretical model. The demand equations show that while the wage-elasticity of demand is large, they are imprecisely estimated. The relative employment of scientists and engineers is quite sensitive to research and development expenditures as a fraction of GDP, particularly after 1997. The supply equation with a rational expectations formulation yields estimates with the right economic signs, but some of these formulations result in complex roots, which cannot be reconciled with the theoretical model. We then use the estimates here to develop a dynamic impulse response function, so as to investigate the effects of policies such as an increase in R&D expenditure on the demand and supply of Canadian scientists. Looking at the impact of a permanent increase in allocation towards R&D, say due to a change in long-term policy, we find that the adjustment process is relatively smooth and the market adjusts in about 2 to 8 years (plus the four years of natural lag in production) to within 80% of the final steady state. For a one-time improvement in R&D allocation , we find that under rational expectations, there is an initial increase in the number of science graduates, but then it falls to below the steady state value and remains there for a long period as the initial increase works its way through the market.

We begin by laying out the theoretical framework for the study.

2 Outline of the Theoretical Model

For our project, we employ the framework for analyzing occupational choice developed by Ryoo and Rosen (2004). In this model, the demand for engineering services, as captured by the engineering wage in period t, W_t, is related to the existing stock of engineers, N_t, and such factors as expenditure on R&D, defence expenditure etc. which affect the demand for engineering services. Capturing these other demand-shift factors by y_t, the inverse demand curve for engineers is given by:

$$W_t = -\alpha_1 N_t + \alpha_2 y_t \tag{1}$$

On the supply side, enrollments in engineering programs, s_t, (or equivalently, the supply of new engineers, assuming constant drop-out rates) is determined by the expected life-time earnings in engineering, V_t, supply shifters such as career prospects in alternative professions, x_t , and previous years' entrants, s_{t-1}. Past enrollments capture the effect of adjustment lags in school capacity as well as peer group effects; for example, high enrollment in a particular year may signal popularity of the subject to potential applicants the following year. Thus, the supply curve for engineers is given by:

$$s_t = \gamma V_t - \rho x_t + \phi s_{t-1} \tag{2}$$

Note that the presumption is that better prospects in engineering as well as peer-group effects (a higher s_{t-1}) increase enrollment, while more attractive prospects in other professions decrease enrollment in engineering.

Finally, the stock of engineers and the flow in the form of new entrants are related by a constant-depreciation inventory formula:

$$N_{t+k} = (1-\delta)N_{t+k-1} + s_t, \tag{3}$$

where δ is the one-period exit rate for engineers (either through retirement or movement to other professions). Since there is a k-period lag (usually $k = 4$ in Canada) between the decision of students to enroll in engineering programs, and actual entry into the professional market, the entry decision in period t, W_t, affects the stock of engineers in period $t + k$.

Defining expected career prospects in engineering by

$$V_t = E_t \left[\sum_{i=k}^{\infty} \beta^i W_{t+i} \right] \quad (4)$$

now completes the specification of the model. In this model, future career prospects affect current enrollment decisions, while the current supply affects the future stock of engineers and hence future wages. Thus, enrollment decisions in various periods are related through the market equilibrium.

Using (3) recursively, we get:

$$E_t(N_{t+k}) = (1-\delta)^k N_t + (1-\delta)^{k-1} s_{t-k+1} + \ldots + s_t$$

Thus the expected stock of engineers in any period $t + k$ depends not only on the stock in period t, but also on all the engineering students in the pipeline. The model can be solved to show (see Ryoo and Rosen (2004) for a detailed solution of the model) that $E_t(N_{t+k})$ follows a second-order stochastic process, and using this other endogenous variables such as V_t, the expected lifetime earnings in engineering, and s_t, the supply of new entrants into engineering schools, can be determined. As is intuitively expected, enrollment into engineering is lower when prospects in other professions, x_t, is higher or when they expect to face a higher stock of engineers upon graduation, i.e. when $E_t(N_{t+k})$ is high. Greater anticipated demand for engineering services in the future i.e. $E_t[\sum_{i=0}^{\infty} y_{t+k+i}]$ also serves to raise entry into engineering.

For empirical estimation both on the demand and supply side, it is easier to formulate the model in relative terms i.e. in terms of the log of the wage of engineers relative to university graduates in general, w_t, log of the number of engineers to the number of university graduates, n_t, the fraction of total university enrollment into engineering programs, π_t, and relative demand shifters such as the percentage of GDP devoted to R&D and defence expenditures, y_t. Adding disturbance terms ε_t and η_t, the demand and supply equations to be estimated are:

$$w_t = -\alpha_1 n_t + \alpha_2 y_t + \varepsilon_t \quad (5)$$

$$\pi_t = \gamma v_t + \phi \pi_{t-1} + \eta_t \quad (6)$$

where v_t is prospects in engineering *relative* to that in other professions. Similarly, we can write the stock-flow equation in relative terms (i.e. engineers relative to university graduates), and taking $k = 4$ (the standard length of an engineering program), equation (3) becomes:

$$n_{t+4} = a_t n_{t+3} + c_t \pi_t \tag{7}$$

where $a_t = (1 - c_t)(1 - \delta)(1 - \delta_g)$, with δ_g being the exit-rate for university graduates, and c_t the ratio of new university graduates to the existing stock of university-educated graduates.

Solving the model using these relative variables, Ryoo and Rosen (2004) show that the fraction of total university enrollment into engineering programs in period t, π_t, is of the following form:

$$\pi_t = \phi\pi_{t-1} - \tau E_t(n_{t+4} - \beta\theta_1\theta_2 n_{t+3}) + \alpha_2\gamma\beta^4 E_t(\sum_{i=0}^{\infty}\theta_3^{-i} y_{t+4+i}) + \eta_t$$

where $\tau = \alpha_1\gamma\frac{\beta^4}{(1-\beta\theta_1)(1-\beta\theta_2)}$, and $\theta_1, \theta_2, \theta_3$ are the roots of the second-order process that n_{t+4} follows. Again, π_t is positively related to enrollment in the previous period, π_{t-1}, implying persistence in the process. It is negatively related to $E_t(n_{t+4})$, the relative stock of engineers they expect to encounter on graduation 4 years later, and is positive with better lifetime earnings prospects $E_t(\sum_{i=0}^{\infty}\theta_3^{-i} y_{t+4+i})$.

Specifying the expectation formation process is necessary for the empirical formulation. This is not as straight-forward as there is a long gap between the decision to enroll and the actual entry into the job-market. Furthermore, the relative inexperience of the decision-making individuals (the students) and finding a balance between one's inherent interests and career prospects can make this a complicated decision problem. Two possible formulations that are popular in the literature are (i) rational expectations, and (ii) static expectations.

In the *rational expectations* solution, the demand and supply shifters, y_t, and x_t, are assumed to follow certain stochastic processes (say, $AR(1)$), and the expected future earnings are determined so that they are internally consistent with the demand-supply equilibrium. This of course assumes that the entrants have very detailed knowledge so as to be able to rationally forecast future earnings. Pashigian (1977), Siow (1984), Zarkin (1985), Pierce (1990) use this structure in their formulation of the occupational choice problem. From (4), we have:

$$V_t = \beta^4 E_t[(1 + \beta L^{-1} + \beta^2 L^{-2} + \ldots)W_{t+4}] = \beta^4 E_t[\frac{W_{t+4}}{1 - \beta L^{-1}}] \quad (8)$$

where $E_t(W_{t+4})$ is the true mean of the realized wage in each subsequent period.

Given the relative inexperience of high-school students in making such decisions, another common assumption is that of *static expectations*, in which information about the future is ignored and expected future earnings are based only on the current wage i.e. entrants believe that $E_t(w_{t+i}) = w_t$ for all i. Thus in this case, entrants are myopic and use only the current or slightly earlier experience in determining the long-term state of the market. Freeman's (1976) original study used this type of "cobweb" expectation formulation. Ryoo and Rosen (2004) use both the rational expectations as well as the static expectations structure to see which fits better the engineering labor market.

In the case of static expectations we have:

$$V_t = \beta^4 E_t[W_{t+4} + \beta W_{t+5} + \beta^2 W_{t+6} + \ldots] = \beta^4[\frac{W_t}{1 - \beta}] \quad (9)$$

as $E_t(w_{t+i}) = w_t$ for all i.

Incorporating the two lifetime expected earnings expressions (8) and (9) into the relative supply equation (6) yields it in an observable form:

$$E_t[(1 - \phi L)(1 - \beta L^{-1})\pi_t] = \gamma\beta^4 E_t[w_{t+4}] \quad (10)$$

under *rational expectations*, and

$$E_t[(1 - \phi L)(1 - \beta)\pi_t] = \gamma\beta^4 w_t \quad (11)$$

under *static expectations*. The main difference between the two is while the static expectations formulation contains only current and backward looking terms i.e. π_t

and π_{t-1}, the rational expectations formulation uses both current, backward *and* forward looking terms i.e. π_t, π_{t-1} *and* π_{t+1}.

Another form of expectations that is sometimes used, especially in the context of inflation and income, is adaptive expectations. In this formulation, the current expectation about future outcomes reflect past expectations as well as an error adjustment term:

$$E_t(w_{t+1}) = E_{t-1}(w_t) + \lambda[w_t - E_{t-1}(w_t)]$$

where $\lambda \in (0,1)$ is the adjustment speed. Iterating this backward implies that $E_t(w_{t+1}) = \lambda \sum_{j=0}^{\infty}(1-\lambda)^j w_{t-j}$. Thus current expectations are a weighted combination of all past outcomes. Incorporating this into the expected lifetime earnings V_t yields it as a geometric weighted average of all past wages w_{t-j}.

3 Data

Consistent estimation of the model requires a significantly long time-series of yearly earnings data and stocks of engineers along with enrollment information and demand and supply shifters such as earnings in other professions, share of GDP spent on R&D, defence etc. Among these, the most difficult to obtain was consistent occupational earnings data. While Ryoo and Rosen (2004) use salary surveys conducted by the National Society of Professional Engineers in the US for their study, comparable salary surveys in Canada are not available. Although some of the provincial professional engineer associations (e.g. the Ontario Society of Professional Engineers) do conduct membership salary surveys, these are not conducted with regularity in all provinces and furthermore, such surveys are recent phenomenon thereby ruling out time-series data of any significant length. Similarly, Census data is to be found only at five-year intervals and therefore cannot be used to study year-to-year variations.

Earnings data: For 1976-1996, we use data from the *Survey of Consumer Finances* (SCF) with the average household head's total earnings used as the income measure.

The average earnings of university graduates is calculated as the average of those who have at least a bachelor's degree. Either RECODED EDUCATION LEVEL (1976-1992) or SUMMARY EDUCATION LEVEL (1993-1996) is used as the education level. Note that the computed average wage includes those with a bachelor's degree only as well as those with a master's and higher-level degrees. This is because the education data in the SCF do not distinguish between these degrees. Missing data (1978 and 1980) are imputed.

One potential source of data problems in the SCF is that in 1989, some changes were instituted in the way information about post-secondary education was collected and reported (Bar-Or et. al. (1995) contains a detailed discussion on these changes). Among the changes, the one that is relevant for this study is that from 1989 onwards, the "university degree" category was explicitly associated as being with a bachelor's degree i.e. it became more restrictive. Thus, in the data there was a slight drop in this category between 1989 and 1990. For our study however, the relevant variable is the *ratio* of those with science and engineering degrees to those with university degrees. Both the denominator and numerator are likely to be affected by this change in definition, and overall this ratio is unlikely to be significantly affected. We also verified this by regressing separately the numerator, denominator and the ratio on a dummy variable accounting for this change. While the dummy variable was negative and significant for the number of science graduates and for the number of university graduates overall, for the ratio of the two, the effect was insignificant and close to zero. The estimated equation was (t-statistics are in parentheses below):

$$\underset{}{ratio} = \underset{(0.36)}{-0.31} \quad \underset{(0.34)}{-0.002} * (dummy) + \underset{(0.49)}{0.0002} * (year)$$

The SCF classifies occupations by the 1980 Standard Occupational Classification. The closest in classification for our purposes is those whose main job is classified as "2: Natural Sciences/Engineering/Mathematics". Thus it includes not only engineers, but also natural scientists as well as mathematicians. The description perhaps fits better the term "scientists" and in the absence of more detailed data, this is what we use for our study. Average earnings of scientists is calculated as the average earnings of those who have at least a bachelor's degree and whose occupation at the main job is classified as "2: Natural Sciences/Engineering/Mathematics".

For 1997-2004, we make use of data from the *Labour Force Survey* (LFS). The SUMMARY EDUCATION LEVEL of the SCF corresponds well with the educational classifications in the LFS data. Unfortunately however, the occupational classification is slightly different here. The LFS classifies data according to the 1991 Standard Occupation Classification, and the closest fit for our purposes is "6: Natural and Applied Sciences and Related Occupations". Although there are some discrepancies with the 1980 SOC, the degree of overlap is fairly large, and for the purpose of extending our time-series data (which is crucial for any hope of significance as regards the empirical analysis), we merge data from the LFS with the pre-1997 data from the SCF. Scientists here are classified as those who have at least a bachelor's degree and whose occupation at the main job is classified as "6:Natural and Applied Sciences and Related Occupations". Annual earnings is computed as usual hourly earnings (variable name: HRLYEARN)) times actual hours per week at the main job (variable name: AHRSMAIN)), times 52. Similarly we obtain average earnings data for all university graduates.

Stock of scientists: We use data from the *Labour Force Survey* to determine the stocks of scientists. For 1976-1996, those (appropriately weighted) who have at least a bachelor's degree and whose occupation at the main job is classified as "2: Natural Sciences/Engineering/Mathematics" by the 1980 Standard Occupational Classification are selected. For 1997-2004, those who have at least a bachelor's degree and whose occupation at the main job is classified as "6: Natural and Applied Sciences and Related Occupations" in the 1991 Standard Occupation Classification are selected.[1]

[1] The Census also contains similar information, but at 5-year intervals. To compare the data

Supply of scientists: We use data from *Education in Canada* over the period 1979-2000 to obtain the number of total (university) bachelor degrees awarded and the number of bachelor degrees conferred in natural sciences. The latter is calculated as the sum of conferred bachelor degrees in Agriculture and Biological Sciences, Engineering and Applied Sciences, and Mathematics and Physical Sciences.

Demand shifters: Data on demand shifters such as R&D expenditure on natural sciences and engineering, Canadian defence expenditure and the Canadian Nominal GDP are relatively straight-forward to obtain from CANSIM.

4 Estimation

4.1 Stock-Flow Dynamics

Figure 1 plots the new entry of scientists along with the relative stock of scientists. For the period after 1980, the two series track each other fairly well with a lag. The flow is high when the stock is low, and the increase in flow is reflected in an increase in stock a few years later.

We begin by estimating the stock-flow relationship between the ratio of science graduates to university graduates and stocks of the same i.e. equation (7). This will help determine how much does entry by fresh science graduates out of Canadian universities account for the dynamics in the market for scientists. Table 1 reports the results. The dependent variable in table 1 is the log of the ratio of the stock of scientists to university graduates in each year (n_t). The independent variables are the lagged value of the dependent variable (n_{t-1}), the log of the ratio of science degrees

obtained from the SCF and LFS with Census data, we derived from the Census the ratio of the stock of engineers and scientists (with an university degree) to all with an university degree. The following table gives the comparison:

	1981	1986	1991	1996	2001
Census	0.108	0.102	0.097	0.098	0.117
SCF/LFS	0.115	0.099	0.109	0.086	0.118

to all university degrees (π_t), and a dummy variable that takes value 1 if the year is 1997 or later. The dummy variable is included in the regression in order to control for changes in the SOC classification from SOC80 to SOC91 in 1997. The coefficients a_t and c_t in (7) are taken as constants as a first approximation.

Table 1

Stock-Flow Dynamics: Equation (7)

	Level		
	OLS	OLS	GMM
	(1)	(2)	(3)
Intercept		-.506	.326
		(1.15)	(.57)
Log(scientists/ univ.	.942	.824	1.068
graduates)$_{t-1}$	(13.78)	(6.46)	(8.49)
Log(science degree/	.089	-.057	.111
univ. degree)$_t$	(0.91)	(0.35)	(0.40)
Dummy(year≥1997)	.135	.135	.139
	(3.06)	(3.82)	(2.49)
R^2	.99	.71	.65
Durbin-Watson	2.08	1.90	2.15
J-statistic	OLS	OLS	3.54
p-value	OLS	OLS	.17

Note: the left-hand side variable is log(scientists/univ. graduates)$_t$.

Absolute t-statistics are in parenthesis.

In OLS estimation, heteroskedasticity-consistent standard error estimates are used.

The GMM instruments are (R&D/GDP)$_{t-1}$, (R&D/GDP)$_{t-2}$, (defense/GDP)$_{t-1}$, and (defense/GDP)$_{t-2}$.

Table 1 uses non-detrended data. Columns 1 and 2 report the results of ordinary least squares (OLS) estimation. In view of a possible correlation between the disturbance term and the regressor (the lagged dependent variable), we also estimate equation (7) by the generalized method of moments (GMM) and report the results in column 3. In the GMM estimation, lagged values of demand shifters such as the R&D/GDP ratio and the defense/GDP ratio are used as instrumental variables. These variables were chosen because they are largely determined by government policy and are hence presumably orthogonal to the disturbance term and yet affect the demand for engineering and scientific services.

Using the non-detrended data, the estimates of a are around 0.9, supporting the intuitive expectation that fresh graduating scientists contribute much less to the dynamics than changes in the stock. This estimate of a is also in line with the findings of Ryoo and Rosen (2004) for the US market. The estimates of c (the contribution of fresh graduates to the dynamics) vary depending on the specification and estimation method used but are insignificant in all cases. These insignificant estimates are probably due to the relatively small number of observations (22 observations) and the relatively large magnitude of the disturbance terms (errors) when we fit equation (7) to the actual data.

However, in spite of (i) the various assumptions regarding occupational and enrollment definitions, and (ii) the first-order assumption made about a constant c, the fit is fairly good, as reflected in the various fit-statistics reported at the bottom of the table.

4.2 Demand for Scientists

Figure 2 plots the log of the relative stock of scientists alongside one of the demand shifters, the log of the ratio of R&D to GDP. The increase and decrease of the R&D expenditure over the period 1997-2004 are reflected well by changes in the number of scientists; when the share of GDP spent on R&D is high, so is the employment of scientists. However, for earlier periods, the co-movement of the R&D expenditure and the stock of scientists are not very clear from this simple visual exercise.

The use of SOC 1980 classification for 1976-1996 and SOC 1990 for 1996-2004 appeared to have caused some discontinuity in the data of the stock of scientists, as can be seen from a 'jump' in the plot. Therefore, a dummy variable is incorporated in the regression analysis to accommodate this effect. In the regressions that follow, we also use the ratio of R&D expenditures to GDP as a demand shifter.

Table 2

Demand Function: Equation (5)

	Inverse Demand: $\omega_t = -\alpha_1 n_t + \alpha_2 y_t$		Demand: $n_t = -(1/\alpha_1)\omega_t + (\alpha_2/\alpha_1)y_t$	
	1976-2004	1997-2004	1976-2004	1997-2004
	(1)	(2)	(3)	(4)
n_t	-.164	-.090		
	(1.50)	(1.74)		
ω_t			-2.893	-1.905
			(1.60)	(1.30)
y_t	.093	.126	.119	.589
	(2.32)	(6.39)	(.42)	(3.60)
Dummy(year≥1997)	.065		.325	
	(1.99)		(6.06)	
R^2	.80	.79	.30	.70
Durbin-Watson	1.35	1.50	1.29	2.34
J-statistic	1.95	2.47	3.02	4.17
p-value	.38	.29	.22	.12
std. error of estimate	.024	.009	.089	.036

Note: absolute t-statistics are in parenthesis.

In OLS estimation, heteroskedasticity-consistent standard error estimates are used.

The instruments are $(\text{R\&D/GDP})_{t-1}$, $(\text{R\&D/GDP})_{t-2}$, $(\text{defense/GDP})_{t-1}$, and $(\text{defense/GDP})_{t-2}$.

Table 2 reports the GMM estimates of the demand function for scientists, namely equation (5). The estimation here is of the limited information type. Since this method can be sensitive to normalization, we report estimates for both the inverse demand and the demand functions. As in table 1, the lagged values of demand shifters are used as instrumental variables.

As can be seen from column 1 (the inverse demand function), the coefficients α_1 and α_2 have the right sign with the stock of engineers having a negative effect on wages (with an elasticity of 0.16) and the demand shifters having a positive effect. Since there is a jump in the relative stock of scientists in 1997 (owing perhaps due to the definitional change), we also estimated the inverse demand function separately using the data for 1997-2004. The results are reported in column 2. Again the coefficients have the expected signs; however, the effect of R&D/GDP on wages is now much stronger, in line perhaps with the hypothesis of recent movement towards a more research and knowledge-driven economic environment where expenses on R&D affect more directly the demand for scientists.

Columns 3-4 report the results for the direct demand function. Although the signs on the coefficients are the same as for the inverse demand function, the estimates of the elasticity of the demand for scientists are now in the range $[-2.8, -1.9]$, and are thus lower than those for the inverse elasticity (ideally these should be inverses of each other). Ryoo and Rosen (2004) report the (direct) elasticity of the demand for the US market as lying in the range $[-2.2, -1.2]$. Thus, even if one were to adopt the more conservative estimates here, we may conclude that relative employment of engineers is quite sensitive to their relative wages and to expenditures on research and development, particularly after 1997.

4.3 Supply of Scientists

Figure 3 plots the fraction of new scientists (the number of conferred degrees in Agriculture and Biological Sciences, Engineering and Applied Sciences, and Mathematics and Physical Sciences relative to all fields) alongside the relative earnings of scientists at the time the students entered university. From 1976 to 1989, the two series follow each other very closely suggesting a close link between earnings and supply. However in the early 1990s, the relative supply of scientists dropped sharply, while the relative earnings of scientists increased. The reason for this drop of the relative supply in spite of a favorable earnings opportunity is not clear, but since the middle of the 1990s, both series have again been trending together.

Table 3 reports the GMM estimation results of the Euler equation variants of the supply function (6). As discussed earlier, while a *static expectations* formulation contains only current and backward looking terms, the *rational expectations* framework uses both current, backward as well as forward looking terms. Panel A specifies exclusively backward-looking structures. Panel B estimates exclusively forward-looking structures, while panel C specifies a structure with both forward- and backward-looking parts. The lagged demand shifters are used as instruments for panels A and B. For panel C, the lagged values of the relative supply is added to the instruments to help identify additional coefficients.

Columns 1-4 report the estimation result with backward-looking structures, corresponding to equation (11). The coefficient on the earnings terms are not estimated statistically significantly (and many have the wrong sign), when either the earnings at the time of entering university, w_{t-4}, or the expected earnings at the time of graduation, w_t, are used. The estimates support the specification with a second-order serial correlation in π_t (column 3), although the coefficient on the earnings term is still very imprecisely estimated (and with the wrong sign).

The estimates in column 3 produce complex roots in the dynamics of π_t. According to Ryoo and Rosen (2004), this is inconsistent with the theoretic model, because the theoretical model here has real roots even in the face of cobweb expectations meaning that cycles should not be produced in the structural supply or demand equation. We conjecture these estimated complex roots arise from a cyclic movement in the relative science degrees observed in the early 1990s (see figure 3). Thus, this could be due to factors outside the present model, and we wish to investigate in the future the effect of including dummies for this period in our estimation.

Table 3

Supply Function: Variants of Equation (6)

	A. Backward-Looking Structure				B. Forward-Looking Structure		C. Backward- and Forward-Looking Structure	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ω_t		.056		-.099	.388		.110	
		(.25)		(.18)	(1.37)		(.89)	
ω_{t-4}	-.195		-.017			.184		.132
	(.76)		(0.10)			(.37)		(.67)
π_{t+1}					.816	1.293	.373	.594
					(3.67)	(2.39)	(1.66)	(7.77)
π_{t-1}	.802	.765	1.497	-.317			.489	.576
	(7.54)	(4.59)	(10.1)	(.12)			(7.06)	(7.47)
π_{t-2}			-.697	.976				
			(3.90)	(.40)				
standard error of estimate	.030	.030	.022	.048	.030	.045	.013	.012
Durbin-Watson	.77	.63	2.30	.50	1.01	.863	1.05	2.45
J-statistic	OLS	1.02	OLS	.28	1.26	2.81	1.11	2.06
p-value	OLS	.60	OLS	.60	.26	.09	.29	.15
Constraints	no	no	no	no	no	no	no	no
Roots	.80	.77	$.75 \pm .37i$	...	...	.71	2.0,.64	$84 \pm .51i$

Note: the left-hand side variable is $\pi_t = \log(\text{science BA/total BA})_t$.

Absolute t -statistics are in parenthesis.

Dummy variable (year$\geq$1997) is included in all regressions but its coefficients are not reported.

In OLS estimation, heteroskedasticity-consistent standard error estimates are used.

The GMM instruments are $(\text{R\&D/GDP})_{t-1}$, $(\text{R\&D/GDP})_{t-2}$, $(\text{defense/GDP})_{t-1}$, and $(\text{defense/GDP})_{t-2}$ except for columns 7-8, for which $\log(\text{science BA/total BA})_{t-3}$ is used as additional instruments.

Panel B reports the estimation result with an exclusive forward-looking structure, where only the leads of π_t appear in the supply equation. Reassuringly, the coefficients of the current and expected earnings (ω_t and ω_{t-4}) have a positive sign here, which corroborates economic intuition. However, the estimates are again not statistically significant.

The estimates of the model with both forward- and backward-looking parts are reported in Panel C. This corresponds to the rational expectation model i.e. equation (10). The coefficients of ω_t and ω_{t-4} have the theoretically expected positive sign, although neither of them are statistically significant. The coefficients of the leads and lags of π_t are statistically significant. The coefficient estimates in column 7 imply that the dynamic equation has one stable and one unstable root. This is economically sensible, because the stable root corresponds to the backward root and the unstable root corresponds to the forward root (see (10)).

However, interpreting these estimates needs some caution. The unstable root in column 7 takes the value of $(0.5)^{-1}$. If we interpret this as the reciprocal of the discount factor β associated with the interest rate for unsecured human capital investments, as Ryoo and Rosen (2004) do, then this estimate implies an interest rate of 50 percent and a planning horizon of about two years. This seems to be intuitively too short, even if university entrants are presumably more myopic than average adults. However, Ryoo and Rosen too find an interest rate in the range 20-30%, suggesting a planning horizon of perhaps three to five years.

The coefficient estimate in column 8 implies a complex root, which should be excluded on theoretical ground as outlined above. Ryoo and Rosen handle this problem by reestimating the parameters while *restricting* the roots to be real. This is something we plan to pursue in the future.

Overall, Panel C, which corresponds to a rational expectations formulation, seems to fit better the model in terms of yielding estimates in line with economic intuition.

To estimate the model under adaptive expectations, theoretically we need to include infinitely many lagged values of π_t. In our case, the limited length of the time series restricts the inclusion of long lags. Thus we added π_{t-2} to the right hand side of column (7) of Table 3 and reestimated the model in order to include the possible effect of adaptive expectations. The estimation result is the following:

$$\pi_t = \underset{(0.26)}{0.040\omega_t} + \underset{(2.02)}{0.390\pi_{t+1}} + \underset{(2.41)}{0.987\pi_{t-1}} - \underset{(1.06)}{0.350\pi_{t-2}},$$

(The absolute t-statistics are in parentheses. An intercept and the dummy variable (year$\geq$ 1997) were also included, but not reported here.) The estimate of the coefficient of π_{t+1} remains almost unchanged. The coefficient of π_{t-1} is different from column (7), albeit the corresponding t-statistics decreased, and the coefficient of π_{t-2} is not significantly different from 0. The roots of the implied dynamic system are 0.81 and $0.39 \pm 0.58i$. The existence of the complex roots suggests an endogenous cycle in the system, which is not supported by the theoretical model.

5 Overall Dynamics

Having estimated the stock-flow dynamic equation (7), the demand equation (5) and the supply equation (11) and (10) under static and rational expectations respectively, we are now in a position to determine the overall market dynamics and use it to study the market response to policy changes such as increases in expenditure on R&D etc.

We take equation (1) from Table 1 as the stock-flow equation: $n_t = 0.942n_{t-1} + 0.089\pi_t$, and equation (1) from Table 2 as the demand equation: $w_t = -0.164n_t + 0.093y_t$. From Table 3, we take equation (2) as the supply equation under static expectations: $\pi_t = 0.056w_t + 0.765\pi_{t-1}$, and equation (7) as that under rational expectations: $\pi_t = 0.110w_t + 0.373\pi_{t+1} + 0.489\pi_{t-1}$.

Now incorporating the stock-flow and the demand equations into (11), one can work out the overall dynamic equation under static expectations:

$$\pi_t = 1.706\pi_{t-1} - 0.720\pi_{t-2} + 0.0052y_t - 0.0049y_{t-1}$$

It is thus an AR(2) process with demand shocks in the current and previous periods affecting the current output of scientists (relative to university graduates).

Similarly, under rational expectations, the difference equation representing the overall dynamics is given by:

$$\pi_t = 3.627\pi_{t-1} - 3.837\pi_{t-2} + 1.235\pi_{t-3} - 0.0274y_{t-1} + 0.0258y_{t-2} \qquad (12)$$

This equation has three characteristic roots, all real: $2.049, 0.930$ and 0.648. Using these, we can rewrite (12) as:

$$\pi_t = 1.578\pi_{t-1} - 0.603\pi_{t-2} + B_t$$

where $B_t = \sum_{j=1}^{\infty}(2.049)^{-j}\{0.0274y_{t+j-1} - 0.0258y_{t+j-2}\}$.

Now that the dynamical equations are in place, we can investigate the market response to demand shocks stemming from such policy changes as an increase in expenditure on R&D or defence. For this investigation, we set the initial levels of π_t (note that this is defined as log of the ratio of science degrees to all university degrees) and y_t to 0 for all the previous periods, and plot the dynamics due to (i) an unanticipated permanent change of y_t to 1 for all subsequent periods, and (ii) an unanticipated temporary change in y_t to 1 for the current period only.

The results of the two exercises are plotted in figures 4 and 5 respectively. Figure 4 shows the market adjustment to an once and for all change in y_t from 0 to 1. Given that y_t is the log of the ratio of total R&D to GDP, it thus considers a hypothetical doubling of R&D expenditure (relative to GDP). Figure 4 plots the dynamics of π_t under cobweb (static) and rational expectations, with the values normalized so that the steady state is 1 under both. From the figure, we find that under a static expectations formulation, the adjustment to a steady state is faster than that under rational expectations. However under both formulations, the market adjusts to within 80% of the final steady state relatively fast – 5-6 years for cobweb expectations and 10-12 for rational expectations. Interestingly, the nature of the subsequent adjustment under static expectations involves slight overshooting of the target and then downward revision, while under rational expectations, there is consistently a shortage in the sense that the dynamics approach the steady state from below. In contrast to Ryoo and Rosen's (2004) dynamics for the US labor market, here there is almost a complete absence of cycles. The adjustment process in the Canadian market to a permanent change in y_t thus appears much less volatile; it is gradual but steady in nature. Whether this particular speed of adjustment is optimal or not is beyond the scope of the current model as optimality would require spelling out the consequences (say on productivity, GDP etc.) of a slow or fast adjustment. The current exercise is meant to provide an idea of if left to itself, how long would the Canadian labor market for scientists require to adjust to a regime change.

Figure 5 plots the market dynamics to a one-time unanticipated change in y_t from 0 to 1; for all subsequent periods $t+i$ ($i \geq 1$), y_{t+i} remains at the previous level of 0. As would be expected, this results in a rise in the proportion of university degrees in science, π_t; the dynamics then adjusts back towards the steady state of $\pi = 0$, but the process of adjustment under the two expectations formulations are rather different. Firstly, the effect of a one time doubling of say R&D expenditure is relatively small, about a 0.5 to 0.7 percent increase. Under static expectations, the dynamics adjusts in a smooth fashion, with π returning to within 0.1 percent of the steady state again within 5-6 years. On the other hand, under a rational expectations formulation, while there is the initial rise in the proportion of students graduating in science, this one period rise is followed by a long horizon when this proportion is below the steady state value. Intuitively, there is an initial positive response to an increase in the demand for scientists; but once the one-period increase in y_t is removed and it goes back to its usual steady-state level of $y_t = 0$, there is an over-supply of scientists, wages remain low thus discouraging new students from choosing science. It takes a long time for π to return to its steady state value. This exercise suggests a strong note of caution for policy: any sudden increases in expenditures on R&D without following it up with a sustained high level of expenditure may have long term negative consequences. The process may lead to a long period of shortages.

6 Conclusion

In this paper, we have attempted to estimate a dynamic supply and demand model for a particular high-skill labour market, namely that of scientists in Canada. Our need for significantly long time-series data in order to estimate yearly changes restricted our choice of data. Although we did attempt to use other data sets for at least some elements of our analysis, ultimately, consistency and length dictated our choice. What we find is that the estimated stock-flow dynamics are supportive of the theoretical model. The demand equations show that while the wage-elasticity of demand is large, they are imprecisely estimated. The relative employment of engineers is quite sensitive to research and development expenditures as a fraction of GDP, particularly after 1997. The supply equation with a rational expectations formulation yields estimates with the right economic signs, but some of these formulations result in complex roots, which cannot be reconciled with the theoretical model.

We then used the estimated stock-flow dynamics, and the demand and supply equations to determine the overall market dynamics and used it to study the effect of different shocks on the dynamics in the Canadian market for scientists. Looking at the impact of a permanent increase in allocation towards R&D, say due to a change in long-term policy, we find that under both expectations formulations, the market adjusts in about 2 to 8 years (plus the four years of natural lag in production) to within 80% of the final steady state. The overall adjustment process is relatively smooth, and is characterized by an approach from below without much overshooting. Looking instead at an one-time increase in allocation towards R&D, we see that while under static expectations, the adjustment process is smooth, but under rational expectations the process involves an initial increase in the number of science graduates, but then it falls below the steady state value and remains there for a long period as the initial increase works its way through the market depressing wages.

So far, we have not distinguished between government and private expenditures on

R&D. Studying the market dynamics of the effects of a change in the two separately would be an interesting issue for future study. Also, while we have focussed here on prospects for Canadian science graduates only in the Canadian market, the US labor market can offer career prospects for at least some of them. Thus a related question is: Do conditions in the US labour market have any effect on enrollment rates in Canadian science and engineering programs? Do Canadian students take into account US market conditions in making their enrollment decisions? We leave this and much else as part of future research in this area.

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8 Appendix: Using "usual hours worked"

In our use of the LFS data from 1997 onwards, we computed annual earnings as usual hourly earnings (variable name: HRLYEARN)) times *actual* hours per week at the main job (variable name: AHRSMAIN)), times 52 (weeks). An alternative would be to use *usual* hours per week in computing this annual earnings figure. While this is not an issue with the SCF data as it records annual earnings directly, it is more of a concern with the LFS data, where the annual earnings are imputed from hourly wage data. In our case however, the variable of concern is the log of the earnings of those with science and engineering degrees *relative* to all with university degrees. The definition affects both groups and so unless the effect differs across them (over time), it should wash out in the ratio. Nevertheless, we re-estimated the model using annual earnings figures derived from *usual* hours per week.

The stock-flow dynamics (Table 1, which does not use earnings at all) are not affected by this change. Re-estimating Table 2, following are the estimates for equation

(1) of Table 2 using this data (absolute t-statistics are in parentheses):

$$w_t = -0.133 * n_t + 0.104 * y_t + 0.033 * (dummy \text{ for } 1997)$$
$$(0.36) \qquad (0.34) \qquad (0.49)$$

Comparing these with column 1 of Table 2, we find some changes in the estimates although qualitatively they are unaffected.[2]

Interestingly, there was no effect of this change in definition on the estimates in Table 3 of the supply equation. The only changes were in the coefficient of the variable Dummy(year $\geq$ 1997), which is not reported in Table 3. We conjecture that the effect of the difference between the two definitions of earnings are mostly absorbed by this coefficient change.

Incorporating this new demand equation into (11), one can again work out the overall dynamic equation under static expectations:

$$\pi_t = 1.706\pi_{t-1} - 0.720\pi_{t-2} + 0.0058y_t - 0.0055y_{t-1}$$

Similarly, under rational expectations, the difference equation representing the overall dynamics is now given by:

$$\pi_t = 3.627\pi_{t-1} - 3.837\pi_{t-2} + 1.235\pi_{t-3} - 0.029y_{t-1} + 0.031y_{t-2}$$

As before, we investigate the market response to demand shocks stemming from permanent and temporary policy changes in expenditure on R&D or defence. These results are plotted in figures 4a and 5a respectively. They are very similar in shape to those in figures 4 and 5. Again, under both static and rational expectations formulations, the adjustment process is relatively smooth and the market adjusts to within 80% of the final steady state in about 5 years for cobweb expectations and 10-12 for rational expectations.

[2] The estimate which is the most affected by this change is the coefficient on w_t in column 4 i.e. the inverse demand function over 1997-2004. Using "usual hours", this estimate changes to -0.23 (with a t-statistic of -0.17). Given that this estimate is generated using only 8 data points as well as instruments, such changes in the estimate due to slight changes in the data may not be too surprising.

Figure 1: New entry flow of scientists and stock of scientists

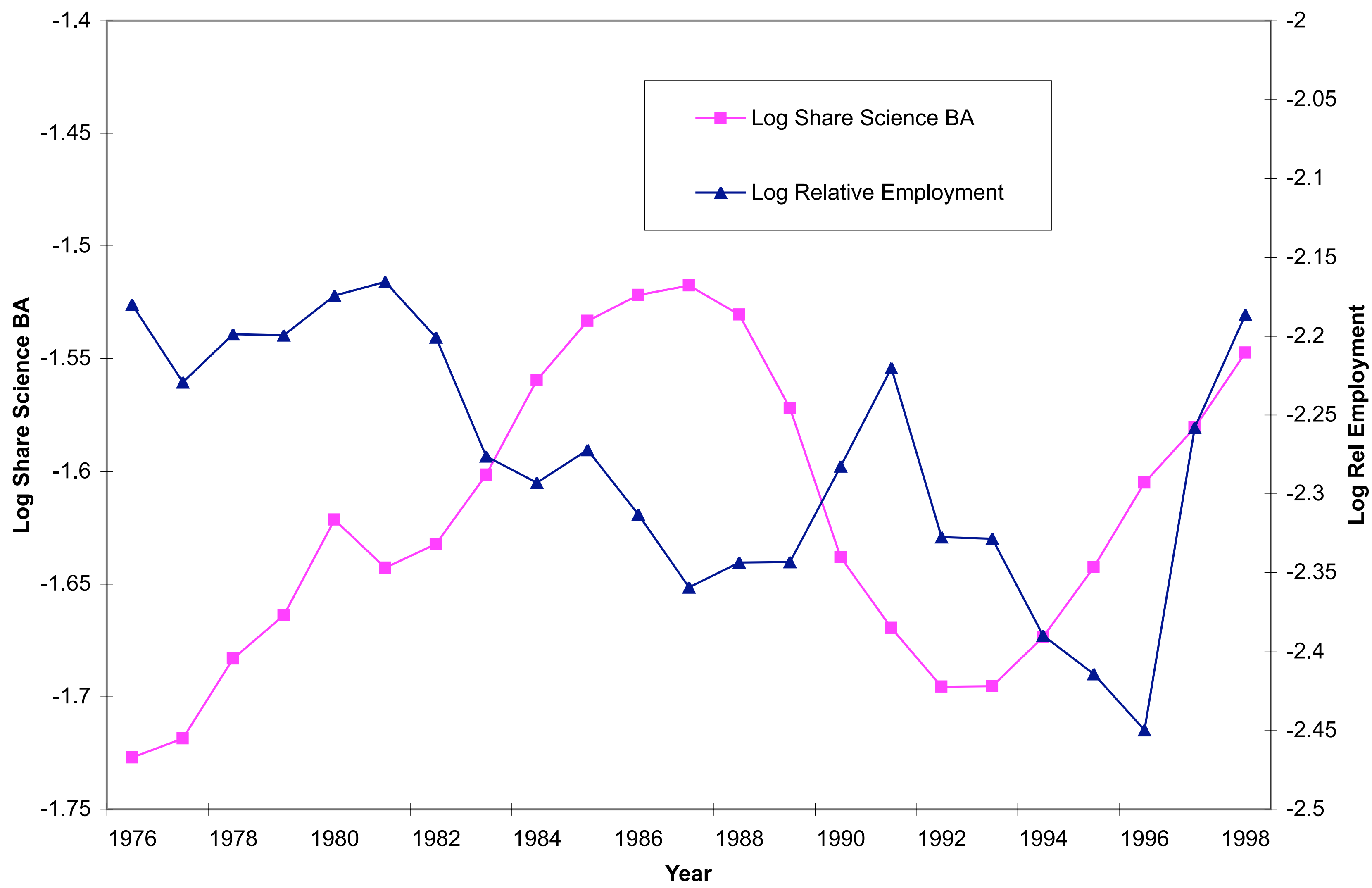

Figure 2: Relative employment of scientists (scientists/college graduates) and relative demand (R&D/GDP)

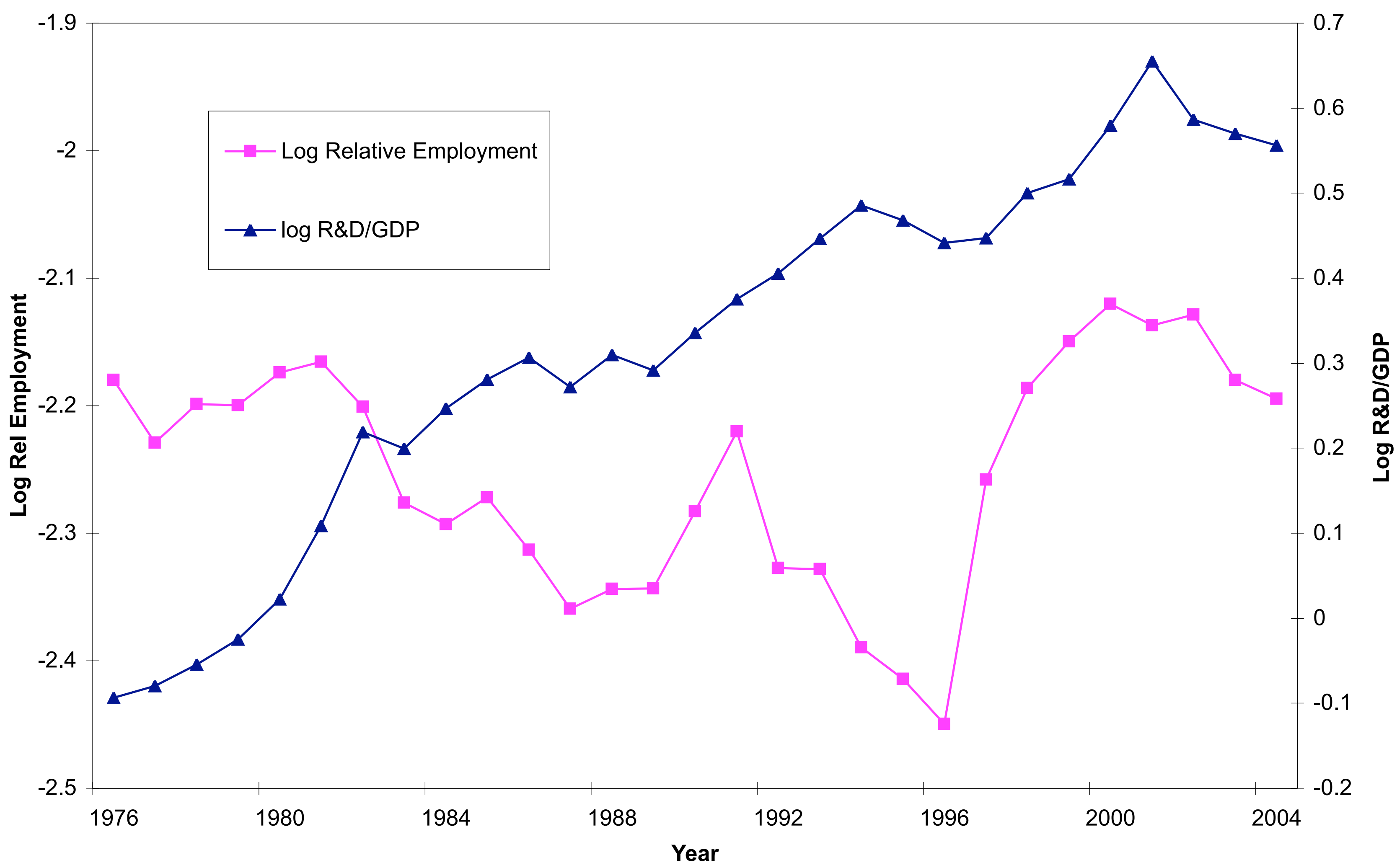

Figure 3: Relative supply of scientists

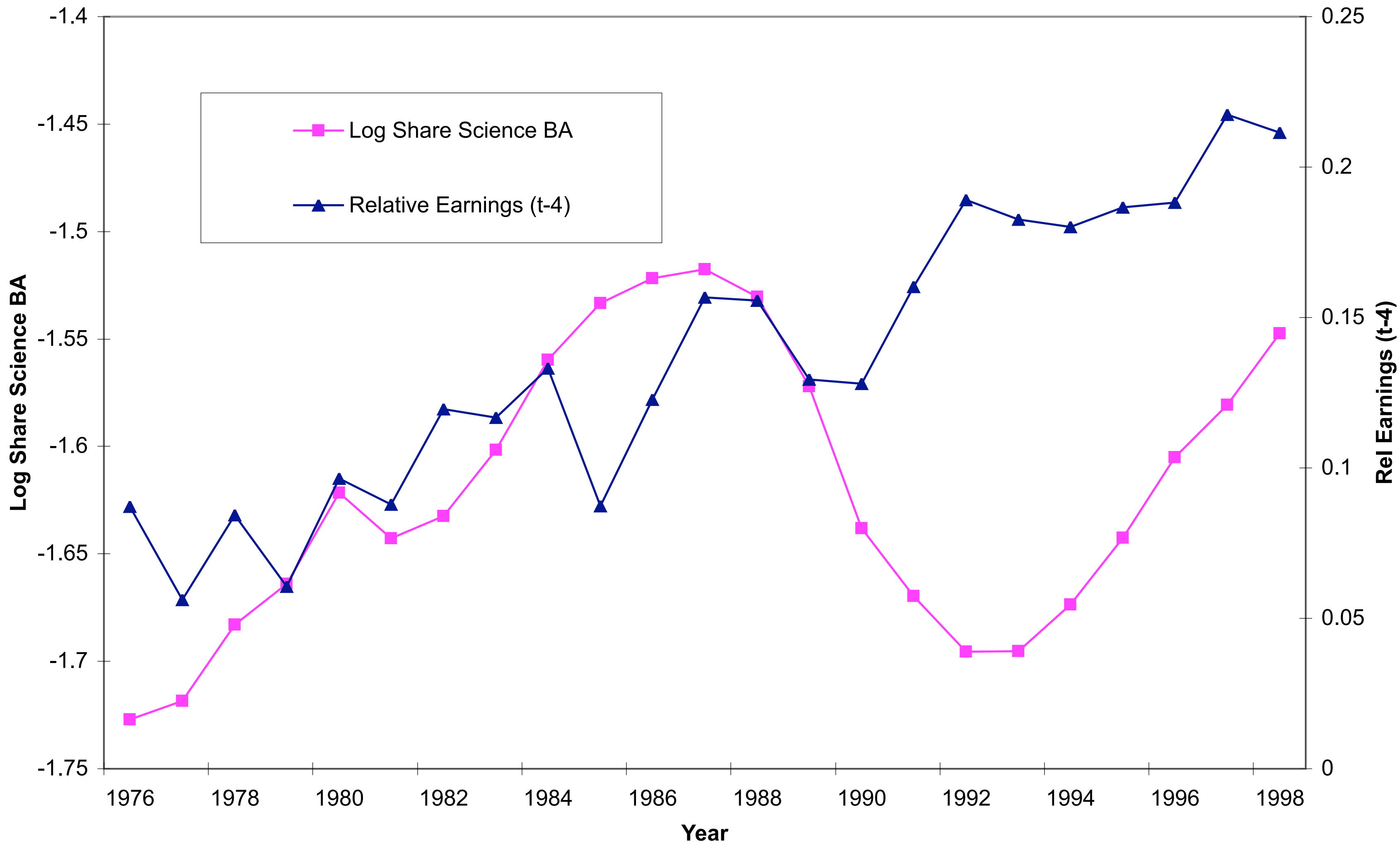

Figure 4: Normalized effect of a permanent change in yt on new entry flows of scientists

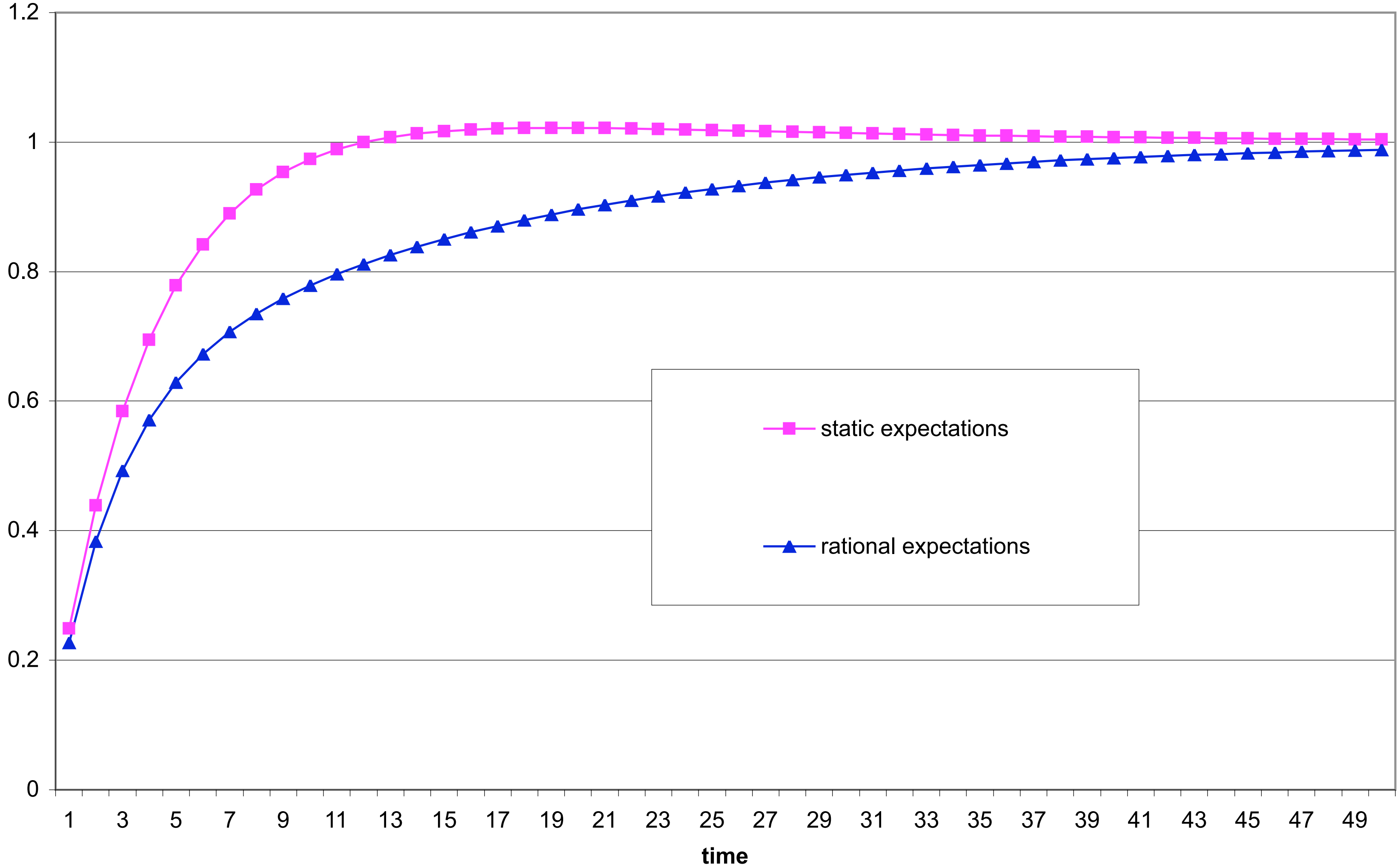

Figure 5: Effect of a temporary change in yt on new entry flows of scientists

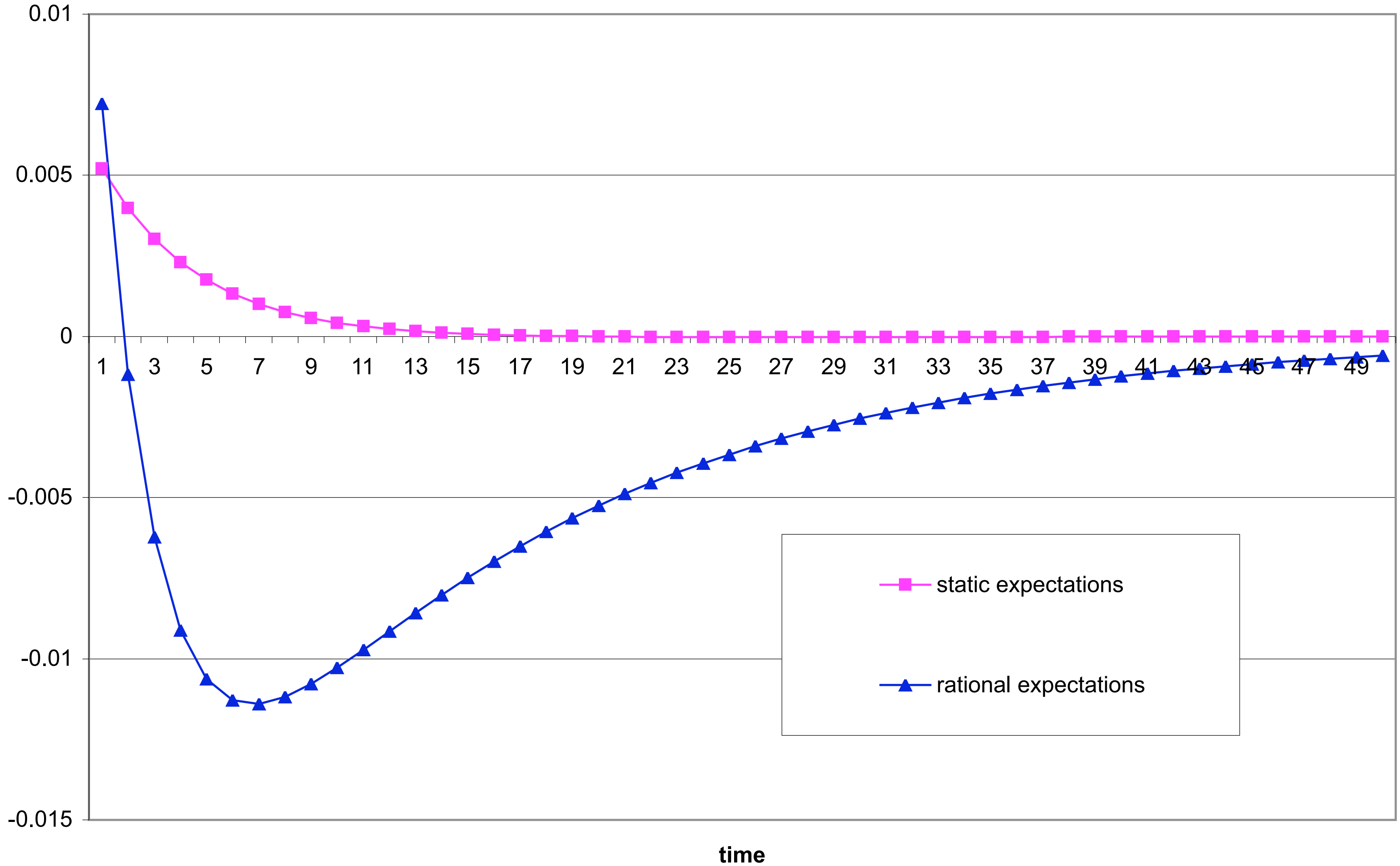

Figure 4a: Normalized effect of a permanent change in yt on new entry flows of scientists (using usual hours per week in computing annual earnings)

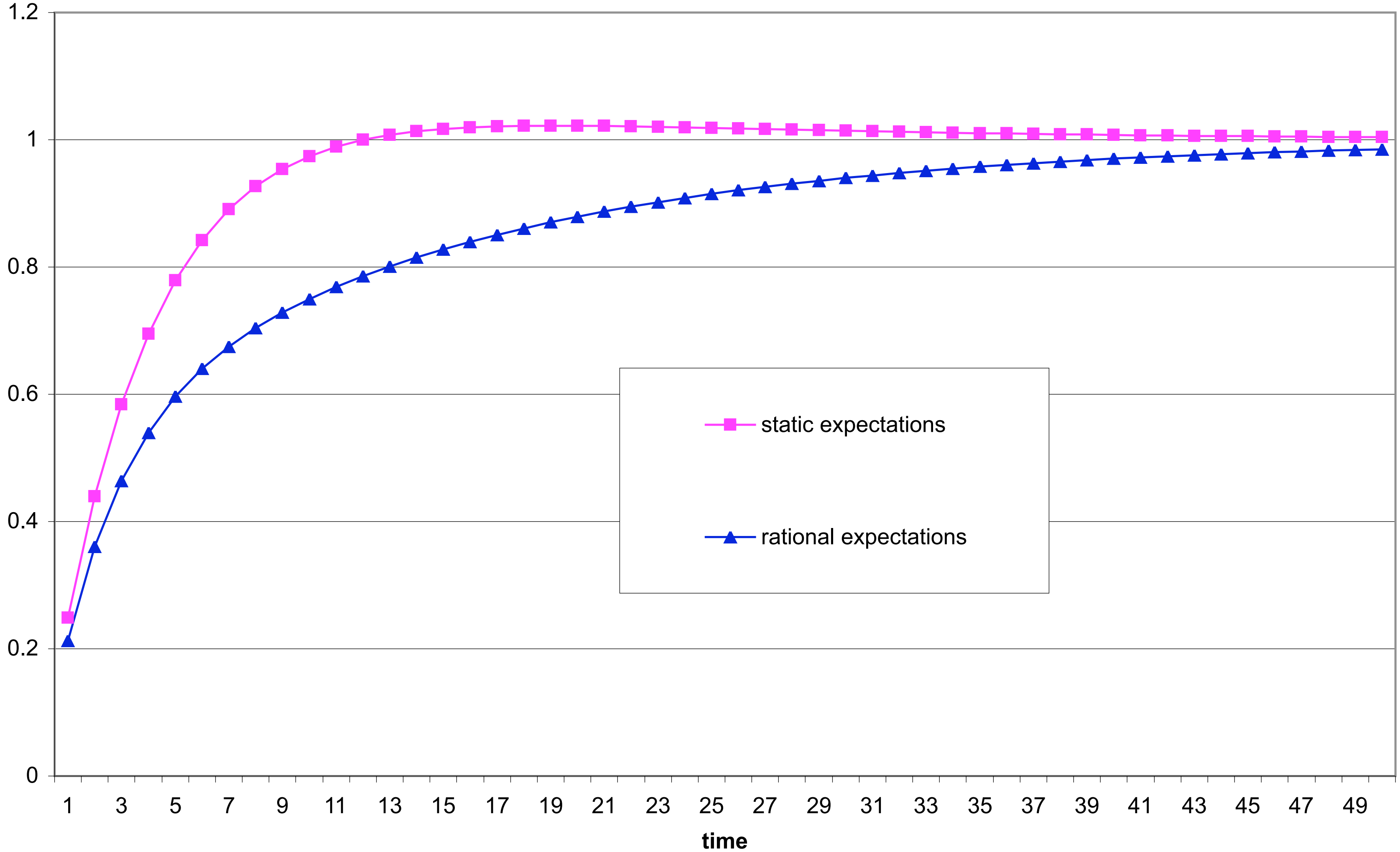

Figure 5a: Effect of a temporary change in yt on new entry flows of scientists (using usual hours per week in computing annual earnings)