Uncertainty and the Specificity of Human Capital*

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Abstract

We argue that the interaction of institutions and shocks can explain why turbulence has had a much larger impact on Japan's economy than on that of the U.S., while Japan outperformed the U.S. prior to the 1980's. The choice between specific and general human capital motivates the choice of institutions. The trade-off between general and specific human capital arises because general human capital, while less productive, can *ex-post* be reallocated across firms. The fraction of individuals with specific human capital depends on the amount of uncertainty in the economy. Our model implies that while economies with more specific human capital tend to be more productive, they also tend to be more vulnerable to turbulence.

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1 Introduction

This paper is motivated by the prolonged stagnation of economic activity observed in Japan since the 1990's. Although various theories have been proposed to explain this lackluster performance, these explanations typically rely on institutions which have been in place since World War II.[1] By contrast, we appeal to the recent increase in economic volatility, a phenomenon which Ljungqvist and Sargent (1998) refer to as *turbulence*, as the driving force behind the recent Japanese economic experience.[2] We argue that the interaction of institutions and shocks can explain why turbulence has had a much larger impact on Japan's economy than on the U.S. economy, together with the fact that Japan outperformed the U.S. prior to the 1980's. The importance of labor market institutions, necessary to support firm-specific human capital, arises endogenously through the choice of specific versus general human capital. We show that economies with more specific human capital tend to be more vulnerable to turbulence due to the inherent difficulty to reallocate such capital. Indeed, the lack of reallocation of labor has long been suggested as a potential cause of Japan' stagnation (e.g., see Kawai (1999) and Kawamoto (2004)).

Our argument is based on the trade-off between firm-specific and general human capital. This trade-off arises in our model because general human capital, while less productive, can be reallocated across firms. Hence, the determining factor for the choice of human capital is the extent of uncertainty about future productivity that firms and workers face when making investment decisions: economies with lower such uncertainty tend to have more workers with specific human capital. We model this idiosyncratic uncertainty by introducing signals about future productivity that firms receive before making human capital investment decisions.

The environment we consider consists of an overlapping generations model where individuals accumulate human capital when young, produce when middle-aged, and retire when old. Cohorts of firms (or projects) are clearly identified with generations of workers. Upon paying a fixed cost of entry, firms receive a signal (good or bad) about their future productivity and hire young workers accordingly. Firms are only

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[1]See Hoshi and Kashyap (2004) and Porter and Sakakibara (2004) for a review. Coleman (2005)'s theory, which revolves around the emergence of China as a major competitor for Japan, is an exception.

[2]See Comin and Philippon (2005) for empirical evidence on turbulence.

productive during the second period of their existence, as are their workers. At the beginning of that second period, firms realize their level of productivity (high or low) and may alter the amount of generalists used in production if desired.

In this model, *ex-ante* idiosyncratic uncertainty determines the allocation of human capital investment. Three types of equilibria may emerge in the model, depending on the expected productivity level of firms with good or bad signals, as well as the relative productivity of specific versus general human capital. The entire equilibrium path for all cases is fully characterized. A key result is that output is higher in economies where signals are more informative. Intuitively, this is true because human capital is better allocated *ex-post* in economies with more precise signals. We also show that under certain conditions, firm-specific human capital is more predominant in economies where signals are more precise.

In our environment, firms and workers sign long term contracts. This market arrangement is essential since firms with good signals who realize a low productivity level end up with more specialists than they would like. Consequently, unexpectedly bad firms would like to dispose of some of their workers who have acquired specific human capital. Furthermore, these long term contracts would be meaningless without commitment, not only from the firm, but also from financial intermediaries (insurers) who end up bailing out firms (and workers) with low realized productivity. As such, the importance of institutions is endogenous in the model.

We use the model to study the impact of turbulence. We model turbulence as a state of the world in which signals carry no information, so that firms with good and bad signals are equally likely to receive a high productivity level. As the precision of signals changes, however, we keep the fraction of firms with high productivity constant. Accordingly, turbulence has no impact in economies where all individuals acquire general human capital. We show that a regime switch from tranquil to turbulent times sends the economy on a smooth path towards a steady state with lower output. The size of the total fall in output during the transition depends on the precision of signals in tranquil times: since output is increasing in the precision of signals, the fall in output is increasing in the precision of signal in tranquil times.

We also study the effects of unexpected transient turbulence. We show that the fall in output during the period of the shock is increasing in the expected precision

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of signals, regardless of whether the economy is in or out of steady state. While the immediate impact of a transient shock is due to the misallocation of labor, its persistence is due to the lower number of entrants, which produces less output, and so on.[3] Under certain conditions, we show that economies with more firm-specific human capital are more productive but more vulnerable to turbulence. As such, our model is consistent with the broad observation that while Japan outperformed the U.S. prior to the 1980's, the U.S. economy was more resilient to the increase in economic volatility after the 1980's.

This paper is related to recent work by Ljungqvist and Sargent (1998, 2004), who argue that the interaction of shocks and institutions can reconcile the European and U.S. unemployment divergence in the last two decades together with the fact that European labor market institutions have been in place since World War II. The central feature of their work is that the human capital of displaced workers is more likely to deteriorate in turbulent times.[4] Although the specificity of human capital is key to their analysis, it is taken as exogenous in their framework. By contrast, we focus on the decision to accumulate general versus specific human capital and their allocation across firms in a model without unemployment. Our results imply that the impact of turbulence critically depends on the amount of uncertainty and the predominance of specific human capital in the economy prior to the shock.

In a context similar to that of Ljungqvist and Sargent (1998), Wasmer (2003) shows that an economy with more general human capital (U.S.) is able to adapt better to an increase in turbulence than an economy with more specific human capital (Europe). While some of our results are similar, we derive our results without appealing to frictions in the labor market, nor do we rely on exogenous government policies. Krueger and Kumar (2003) focus on the U.S.–Europe growth difference since the 1980's. They build a model of education and technology adoption to argue that the European focus on specialized, vocational education might have worked well during the 1960's and 1970's, but not as well during the subsequent information age

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[3]Interestingly, such turbulence shocks generate an increase in transfers from financial intermediaries to unproductive firms, reminiscent of what Caballero et al. (2005) called "zombie" lending.

[4]Using a job matching model with endogenous job destruction, den Haan et al. (2005) argue that if turbulence also affects the skills of workers experiencing endogenous separation, then higher turbulence leads to a reduction in unemployment, thereby reversing the results of Ljungqvist and Sargent (1998, 2004).

when new technologies emerged at a more rapid pace. While the underlying economic mechanism in that paper is quite different from ours, the increased frequency of switching technologies they consider could be interpreted as one of the sources of the increase in uncertainty in our model.

The issues addressed in this paper are quite different from those in the traditional literature on investment under uncertainty (see for example Dixit and Pindyck (1994)). This literature focuses on the need/desire for insurance against idiosyncratic risk faced by investors. By contrast, we consider an environment where investors are able to completely pool idiosyncratic risk, and focus instead on the output (profit) maximizing allocation of the investment. The trade-off we capture is between efficiency and flexibility, which arises as firms and workers choose between general and specific human capital, as in the standard theory of human capital developed by Becker (1964).

The rest of the paper is organized as follows. The next section present the economic environment. A definition of competitive equilibrium is offered in Section 3, where we also prove the first welfare theorem and present some basic results regarding efficient (and thus competitive equilibrium) allocations in this economy. Depending on parameter values, three types of equilibria with different ex-post allocation of general human capital may emerge. Accordingly, in Section 4 we partition the parameter space into three regions and present a general way to find the equilibrium. We also shows that any economy converges at the same pace to its unique steady state, and establish important comparative static results. The impact of turbulence is discussed in Section 5, where we introduce a form of aggregate uncertainty in the model. Concluding remarks are offered in Section 6.

2   The Environment

We consider a closed economy populated by overlapping generations of individuals who live for 3 periods. Individuals invest in human capital when young, work when middle-aged, and retire when old. Human capital investment can be of two distinct types: general and firm-specific. While investment in specific human capital is more productive than investment in general human capital, specific human capital can only

be used by the firm for which it was acquired. By contrast, general human capital is equally productive in all firms. Each period, a single perishable consumption good is produced by a continuum of firms using human capital as the only input. For convenience, we assume that firms also live for three periods. Upon paying a fixed cost of entry, firms draw a signal about their second-period productivity level. Using that information, they choose how many young workers to hire and what type of human capital to employ. At the beginning of the second period, the productivity of the firm is realized, the firm adjusts its labor force if desired, and production takes place.

We assume that firms have access to perfect insurance markets while individuals have no such access. Thus, as long as there is no aggregate uncertainty, firms will offer workers a deterministic wage. We further assume that households cannot borrow and that firms pay young workers they hire an advance on their future wages. In their second period of life, firms pay middle-aged workers their promised wages (less the advance), a fraction of which is saved for retirement. Note that this arrangement is equivalent to one where firms provide workers with retirement benefits, as the cheapest way for firms to deliver a certain reservation utility corresponds to the allocation workers would choose by maximizing their utility on the corresponding budget. The savings of the middle-aged are deposited into a mutual fund which finances new firms who need resources to finance their entry cost and wage advances to young individuals.

2.1 Individuals

There is a continuum (of measure one) of individuals born every period. They live and consume for three periods. During their first period of life, individuals accumulate human capital which becomes productive when middle-aged and depreciates fully when old. All individuals have the same preferences represented by the utility function

$$U(c^1, c^2, c^3) - v(h + g) = \ln c^1 + \beta \ln c^2 + \beta^2 \ln c^3 - \eta(h + g), \tag{1}$$

where c^j represents consumption at age j, h and g respectively represent specific and general human capital acquired when young, $0 < \beta < 1$ is a discount factors and η is the utility cost of accumulating 1 unit of human capital.

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2.2 Firms

Each period a measure of *ex-ante* identical potential entrants (firms or projects) are born. Should they choose to enter, they must pay a fixed cost ϕ. We denote μ_t the measure of firms entering in period $t-1$, as these firms will only produce in period t.

Upon entering, each firm draws an individual signal $s \in \{g, b\}$ about their future productivity, where the good signal g occurs with probability ρ and the bad signal occurs with complementary probability. The actual productivity levels, drawn at the beginning of the following period (t), can also take on two values: $A \in \{A_H, A_L\}$, where $A_H > A_L$. The probability that a firm with signal s draws high productivity is denoted π_s, with $\pi_g \geq \pi_b > 0$. *Ex-post*, the fraction of firms with high productivity is $\overline{\pi} = \rho\pi_g + (1-\rho)\pi_b$.

Given the signal received in period $t-1$, each firm decides how many young workers to hire, and sign binding contracts with these workers specifying the type and amount of human capital to be acquired by the worker as well as payments to workers in the current and future periods. The labor market of young workers is competitive. Once a firm realizes its productivity level A_t, it can hire additional workers with general human capital from other firms or "lend out" its own workers. The market for middle-aged workers with general human capital is also competitive. The production function of an individual firm is:

$$F(H, G) = A\big(H + \gamma G\big)^{\theta}, \tag{2}$$

where H and G respectively denote total stocks of specific and general human capital employed by the firm, $\gamma \in (0, 1)$ measures the relative efficiency of general human capital, and $\theta \in (0, 1)$. This specification implies that firm-specific human capital is more productive than general human capital. The advantage of general human capital is that it offers firms flexibility, as workers with general human capital can be reallocated from unexpectedly unproductive firms to unexpectedly productive ones.

One can think of this environment as follows. In order to get an idea of how productive a project is, a fixed cost needs to be paid (research cost, market analysis, etc.). At this stage labor is allocated among the projects and human capital accumulation choices are made. Firms expecting to be more productive will be larger. In the following period, firms draw their actual productivity conditional on their signal.

Upon realization of the productivity levels reallocation of workers with general human capital takes place.

2.3   Financial Intermediaries

There are several allocation-equivalent ways to model the financial (and insurance) side of our economy. A transparent one is to think of a competitive mutual fund financed or created every period by middle-aged workers. This mutual fund pools future idiosyncratic risk and advances credit to newly created firms.

Entering firms borrow from the intermediary to pay the entry cost. Upon realizing their signal of future productivity, entering firms borrow additional funds to pay young workers they hire. Effectively, this borrowing cannot be disentangled from the insurance against future idiosyncratic productivity shocks that these young firms are purchasing. The "repayment" of these loans is contingent on the realized productivity level next period. In fact, if the dispersion of productivity levels is sufficiently large, firms could even receive further funds from the intermediary next period if their productivity level were very low relative to expectations derived from the signal. But these are financed from extraordinarily high "repayments" from the "lucky" firms and do not involve intergenerational transfers.

The ownership of firms is irrelevant since competitive entry and full insurance against idiosyncratic risk guarantee that their value is zero. One could thus imagine that the mutual fund effectively owns all the firms it finances and receives all their revenues less wages paid. This "ownership" features unlimited liability.

3   Competitive Equilibria

A natural way to decentralize efficient allocations in our environment is for new firms to write long term contracts with their workers specifying payments for the three periods during which individuals live. Each contract is the solution to a firm's profit maximization problem subject to keeping young workers' utility above some reservation value. As will become clear in the next section, the model is much more tractable under an equivalent representation. This representation uses the fact that

firms know precisely the way in which workers want to distribute their resources over their life-time. It follows that firms could equivalently offer workers a single wage payment in either period of a worker's life and let the worker decide on its distribution across periods. In the definition of a competitive equilibrium below, we therefore assume without loss of generality that firms only offer a second period wage to young workers they hire. We denote w_t^H the wage of a worker born in period $t-1$ who accumulates specific human capital and w_t^G that of a worker who accumulates general human capital.

In the environment described above, firms and workers sign long term contracts. This market arrangement is important when there is potential exposure of risk-averse workers to idiosyncratic risk. An important feature of efficient allocations in this economy is that firms with good signals who later realize a low productivity level invariably have more specialists than they would like. Consequently, unexpectedly bad firms would like to dispose of some of their workers who have acquired specific human capital. Since firms but not workers have access to insurance against idiosyncratic productivity shocks, long term contracts between firms and workers are *essential* to decentralize efficient allocations. In addition, long term contracts would be meaningless without commitment, not only from the firm, but also from financial intermediaries (insurers) who end up bailing out firms (and workers) with low realized productivity. As such, the importance of institutions is endogenous in the model.

3.1 Definition

A ***Competitive Equilibrium*** in this environment consists of sequences of prices $\left\{w_t^H, w_t^G, r_t\right\}$, allocations for individuals $\left\{c_{t-1}^1, c_t^2, c_{t+1}^3, h_t, g_t\right\}$ and for firms $\left\{H_t(s), \Pi_t(s), G_t(A, H), R_t(A, H)\right\}$, and aggregates $\left\{\mu_t, M_t\right\}$ such that

1. given prices, individuals' allocations maximize utility subject to their (maximized) present-value budget constraint:

$$\max_{c,h,g}\left[\ln c_{t-1}^1 + \beta \ln c_t^2 + \beta^2 \ln c_{t+1}^3 - \eta(h_t + g_t)\right]$$

$$\text{s.t.} \quad c_{t-1}^1(1 + r_t) + c_t^2 + \frac{c_{t+1}^3}{1 + r_{t+1}} \leqslant \max\left\{w_t^H h_t, w_t^G g_t\right\} \tag{HHP}$$

2. given prices and stock of specific human capital, $G_t(A, H)$ maximizes profits in the second period:

$$R_t(A, H) \equiv \max_{G \geqslant 0} \left[A\big(H + \gamma G\big)^\theta - w_t^G G \right] \tag{FP2}$$

3. given prices, signal and $R_t(A, H)$, $H_t(s)$ maximizes expected present value of profits:

$$\Pi_t(s) \equiv \max_H \left[\mathrm{E}[R_t(A, H)|s] - w_t^H H \right] \tag{FP1}$$

4. expected profits of entrants are zero:

$$\frac{\mathrm{E}[\Pi_t(s)]}{1 + r_t} = \phi \tag{3}$$

5. markets clear:

$$M_t g_t = \mu_t \Big\{ \rho \Big[\pi_g G_t\big(A_H, H_t(g)\big) + (1 - \pi_g) G_t\big(A_L, H_t(g)\big) \Big] + $$
$$(1 - \rho) \Big[\pi_b G_t\big(A_H, H_t(b)\big) + (1 - \pi_b) G_t\big(A_L, H_t(b)\big) \Big] \Big\} \tag{4}$$

$$(1 - M_t) h_t = \mu_t \Big[\rho H_t(g) + (1 - \rho) H_t(b) \Big] \tag{5}$$

$$\frac{c_{t+1}^3}{1 + r_{t+1}} = \mu_{t+1} \phi + c_t^1 \tag{6}$$

where M_t is the fraction of individuals born in $t - 1$ who choose to accumulate general human capital. A few notes are in order. First, since generalists can be freely re-allocated when middle-aged, their distribution across firms when young is irrelevant. Second, whereas the two labor market clearing conditions (4) and (5) are self-explanatory, the last market clearing condition requires some explanation.[5] This condition states that consumption of the old must have been saved in the previous period as this is the only source of income for old individuals. In turn, savings are used either to finance entering firms or to provide young individuals with consumption.

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[5]Note that the labor market clearing conditions (4) and (5) and the budget constraint in (HHP) use Proposition 2, which states that all individuals fully specialize either in specific or general human capital.

3.2 Some Basic Results

Before proceeding to the analysis and implications of the model, we establish some basic results that prove useful in the analysis.

First, because of the linearity of the utility function in human capital, all individuals will accumulate the same amount of human capital, given by $(1 + \beta + \beta^2)/\eta$. We thus normalize $\eta = (1 + \beta + \beta^2)$, so that individuals will accumulate one unit of human capital. Second, we state without a formal proof that whenever both general and firm-specific human capital is accumulated in equilibrium, young workers have to be indifferent between the two types of human capital. It follows that they will receive the same wage regardless of the type of labor services they supply, i.e. $w_t^H = w_t^G = w_t$.

More importantly, the first welfare theorem holds in this environment, as the following Proposition shows.

Proposition 1 *Competitive equilibrium allocations are efficient.*

Proof. Suppose, by contradiction, that there exists a feasible allocation $\{\widehat{c}, \widehat{h}, \widehat{g}, \widehat{\mathcal{H}}, \widehat{\mathcal{G}}, \widehat{\mu}\}$, where $\mathcal{H}_t$ and $\mathcal{G}_t$ respectively denote the aggregate stock of specific and general human capital at date t, such that $u_t(\widehat{c}, \widehat{h} + \widehat{g}) \geqslant u_t(c, h + g)$ with strict inequality for at least one generation. Then $\widehat{c}_{t-1}^1 (1 + r_t) + \widehat{c}_t^2 + \frac{\widehat{c}_{t+1}^3}{1+r_{t+1}} \geqslant w_t(\widehat{h}_t + \widehat{g}_t)$ with strict inequality for at least one generation. Multiplying these inequalities by $\prod_{\tau=1}^{t} \frac{1}{1+r_\tau}$ and summing over generations, we get

$$\sum_{t=1}^{\infty} \left(\prod_{\tau=1}^{t} \frac{1}{1 + r_\tau} \right) (\widehat{c}_t^1 + \widehat{c}_t^2 + \widehat{c}_t^3) > \sum_{t=1}^{\infty} \left(\prod_{\tau=1}^{t} \frac{1}{1 + r_\tau} \right) w_t \left(\widehat{\mathcal{H}}_t + \widehat{\mathcal{G}}_t \right).$$

We first need to show that both summations are finite. Since the economy converges to a steady state (see Proposition 4 in Section 4), we only have to show that the interest rate is strictly positive in that steady state. To see this, note that consumers with logarithmic utility functions allocate income across periods in fixed proportions. If we let W_{ss} denote the steady state lifetime wealth of individuals in terms of young-

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age consumption goods, then

$$\frac{c_{ss}^3}{(1+r_{ss})^2} = \frac{\beta^2}{1+\beta+\beta^2}W_{ss},$$

$$c_{ss}^1 = \frac{1}{1+\beta+\beta^2}W_{ss}.$$

These expressions imply that equation (6) cannot hold in the steady state unless the interest rate is strictly positive.

We will now argue that the equilibrium allocation solves the pseudo-planner's problem

$$\max_{\mu,\mathcal{H},\mathcal{G}} \left[Y_t(\mu,\mathcal{H},\mathcal{G}) - w_t(\mathcal{H}+\mathcal{G}) - \mu\phi(1+r_t) \right]. \tag{7}$$

At the firm level, the equilibrium allocation solves

$$\pi_t = \max_{H,G} \mathrm{E}\left[y_t(H,G) - w_t(H+G) \right].$$

We then have to show that the equilibrium μ_t solves

$$\max_{\mu} \left[\mu\pi_t - \mu\phi(1+r_t) \right].$$

Observe that this maximization problem is concave and that the first order condition with respect to μ

$$\pi_t(\mu) - \phi(1+r_t) = 0$$

is the free-entry condition of the competitive equilibrium. The equilibrium allocation thus solves the pseudo-planner's problem (7).

Hence, $Y_t(\widehat{\mu}_t) - w_t(\widehat{\mathcal{H}}_t + \widehat{\mathcal{G}}_t) - \widehat{\mu}_t\phi(1+r_t) \leqslant Y_t(\mu_t) - w_t(\mathcal{H}_t + \mathcal{G}_t) - \mu_t\phi(1+r_t) = 0.$
It then follows that

$$\sum_{t=1}^{\infty} \left(\prod_{\tau=1}^{t} \frac{1}{1+r_\tau} \right) \left(\widehat{c}_t^1 + \widehat{c}_t^2 + \widehat{c}_t^3 + \phi\widehat{\mu}_{t+1} \right) > \sum_{t=1}^{\infty} \left(\prod_{\tau=1}^{t} \frac{1}{1+r_\tau} \right) Y_t(\widehat{\mu}_t),$$

which contradicts the feasibility of $\left\{ \widehat{c}, \widehat{h}, \widehat{g}, \widehat{\mathcal{H}}, \widehat{\mathcal{G}}, \widehat{\mu} \right\}$. ∎

Since all equilibria are efficient, the following two results apply to every competitive equilibrium allocation. The first result establishes that in any efficient allocation, all individuals fully specialize either in specific or general human capital.[6] The second

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result establishes sufficient conditions for an economy to feature a positive measure of individuals with firm-specific human capital.

Proposition 2 *If $A_L > 0$, efficient allocations cannot have a positive measure of individuals acquiring both specific and general human capital.*

Proof. Suppose, by contradiction, that in an efficient allocation a firm i hires a positive measure λ of individuals who make fraction κ of their human capital investment general and fraction $(1 - \kappa)$ specific. Consider an alternative allocation where $\kappa\lambda$ individuals acquire only general human capital and the remaining $(1 - \kappa)\lambda$ only acquire specific human capital. The alternative allocation results in weakly greater output for all productivity levels, while keeping the cost of acquiring human capital constant. The output of the two allocations is the same if there is no *ex-post* reallocation, and the output of the alternative allocation is greater if some of the workers under consideration are reallocated to other firms. When workers with general human capital are reallocated ($\kappa\lambda$ of them), there is now $(1 - \kappa)\lambda$ workers with specific human capital who remain productively employed in firm i. That portion of the human capital stock was lost during reallocation in the original allocation. Note further that the event in which the reallocation occurs has strictly positive probability, since otherwise firm i would make *all* its employees obtain specific human capital only. It follows that the alternative allocation always delivers at least as much output as the original, and delivers strictly more output (revenue) with strictly positive probability, while keeping the costs constant.[7] This implies that the original allocation could not have been efficient. ∎

Proposition 3 *If $A_L > 0$, then the measure of individuals with specific human capital is strictly positive in any efficient allocation.*

Proof. This follows directly from the fact that once all firms have received their idiosyncratic productivity shock, even the firm with the smallest productivity shock will be operating and so would hire a positive amount of specific human capital. In other words, even if a firms knew for sure that its productivity level tomorrow will be low, it would still want to hire workers with specific human capital. ∎

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[7]Note that if $A_L = 0$, both allocations produce the same output as there is no gain in keeping individuals with specific human capital in unproductive firms.

4 Characterizing Equilibria

In this section we study the different types of equilibria that this economy can generate. Three types of equilibria may emerge, depending on parameter values. In the first two cases, a fraction of individuals acquire specific human capital and the rest acquire general human capital. What differentiates these two cases is whether all *ex-post* productive firms hire generalists or only those who received a bad signal *ex-ante* hire generalists.[8] A special case of an equilibrium in which all high productivity firms hire generalists is one where all individuals acquire general human capital. The last type of equilibrium is one where all individuals acquire specific human capital.

4.1 Solving for an Equilibrium

In Appendix A we show in detail how to construct the full solution to the model for each type of equilibrium. As it turns out, the general way to find a solution is common to all three tyres. The algorithm proceeds as follows.

At the beginning of any period t, the state of the economy is given by the number of firms that entered in the previous period as well as the amount of consumption that is currently promised to the old, (μ_t, c_t^3). We now briefly demonstrate how to obtain (μ_{t+1}, c_{t+1}^3) from the current state.

We show in Appendix A that independent of the type of equilibrium, the labor market clearing condition implies that the wage rate in period t is completely determined by the current measure of producing firms:

$$w_t = \theta(D\mu_t)^{1-\theta}, \tag{8}$$

where D is a constant, the value of which depends on the type of equilibrium. Since the labor share of output is given by θ, i.e. $w_t = \theta Y_t$, we can write aggregate output as a function of μ:

$$Y_t = (D\mu_t)^{1-\theta}. \tag{9}$$

The aggregate disposable income of middle-aged individuals is given by $Y_t - c_t^3 \equiv Y_t^d$. With logarithmic utility functions, middle-aged individuals will save a fraction

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[8]Note that low productivity firms never hire generalists.

of their income, $X_t = \left(\frac{\beta}{1+\beta}\right) Y_t^d$, and consume the reminder, $c_t^2 = \left(\frac{1}{1+\beta}\right) Y_t^d$. The market clearing condition for savings and investment then implies that

$$X_t = \left(\frac{\beta}{1+\beta}\right)(Y_t - c_t^3) = \mu_{t+1}\phi + \frac{w_{t+1}}{(1+r_{t+1})(1+\beta+\beta^2)}. \tag{10}$$

In other words, the resources saved by the current middle-aged will be used to pay the entry cost of firms that will produce tomorrow as well as the consumption of young individuals in period t, which they optimally choose to be a fraction of the wage they will receive tomorrow (see equation (6)).

Next we use the free entry condition to establish a relationship between the interest rate and the measure of entering firms. Expected profits of a firm entering at date t are given by

$$E\big[\Pi_{t+1}(s)\big] = \rho\left(E\Big[A_{t+1}F(H_{t+1}(g), G_{t+1})\big|g\Big] - w_{t+1}\Big(H_{t+1}(g) + E[G_{t+1}|g]\Big)\right)$$
$$+ (1-\rho)\left(E\Big[A_{t+1}F(H_{t+1}(b), G_{t+1})\big|b\Big] - w_{t+1}\Big(H_{t+1}(b) + E[G_{t+1}|b]\Big)\right). \tag{11}$$

Summing over all firms and using market clearing conditions (4) and (5), we have

$$\mu_{t+1}E\big[\Pi_{t+1}(s)\big] = Y_{t+1} - w_{t+1}.$$

The free entry condition (3) can thus be written as

$$\frac{Y_{t+1}/\mu_{t+1} - w_{t+1}/\mu_{t+1}}{1+r_{t+1}} = \phi,$$

or, using (8) and (9),

$$1 + r_{t+1} = \frac{(1-\theta)D^{1-\theta}}{\phi}\mu_{t+1}^{-\theta}. \tag{12}$$

We can now use equation (12) together with the equation for output (9) in equation (10) to solve for the measure of firms that will be producing in period $t+1$:

$$\mu_{t+1} = \Lambda D^{1-\theta}\mu_t^{1-\theta} - \Lambda c_t^3, \tag{13}$$

where

$$\Lambda = \frac{\beta}{\phi(1+\beta)}\left[1 + \frac{\theta}{(1-\theta)(1+\beta+\beta^2)}\right]^{-1}. \tag{14}$$

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Finally, consumption of the old in period $t+1$ is given by the return on the period t savings of the middle-aged, that is,

$$c_{t+1}^3 = \left(\frac{\beta}{1+\beta} \right) (1 + r_{t+1}) \left(Y_t - c_t^3 \right), \tag{15}$$

where r_{t+1} is given by (12).

While this algorithm is independent of the type of equilibrium, the constant D does depend on the the type of equilibrium under study, which itself depends on parameter values. We now partition the parameter space into three regions corresponding to each type of equilibrium.

4.2 Types of Equilibria

Parameter values completely determine the type of equilibrium we obtain. As Proposition 3 shows, an economy in which all individuals acquire general human capital can only occur if the low productivity level is zero ($A_L = 0$). Otherwise a positive fraction of individuals will be specialists. Let $E_g = E[A|s = g] = \pi_g A_H + (1 - \pi_g) A_L$ and $E_b = E[A|s = b] = \pi_b A_H + (1 - \pi_b) A_L$ denote the expected productivity level of a firm with a good and bad signal, respectively. We show in the Appendix that when the ratio of relative productivities is such that

$$E_g < \gamma A_H, \tag{16}$$

then the equilibrium is one where all firms with a high realized productivity level, regardless of the signal they received, hire generalists. Similarly, when the relative productivities is such that

$$E_b < \gamma A_H \leq E_g, \tag{17}$$

then the equilibrium is one where only firms that received a bad signal but a high realized productivity level hire generalists. Finally, if

$$\gamma A_H \leq E_b, \tag{18}$$

then all individuals will be specialists.

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It should be noted that these conditions completely characterize the path of the economy, in the sense that if we start in one of these cases, the economy will remain in that case.[9] Table 1 summarizes the types of equilibria that can occur in this economy.

Table 1: Types of Equilibria

Type	Description	Condition
Type 1:[a]	All high productivity firms hire generalists	$E_b < E_g < \gamma A_H$
Type 2:	Only high productivity firms who received bad signal hire generalists	$E_b < \gamma A_H \leq E_g$
Type 3:	All individuals are specialists	$\gamma A_H \leq E_b < E_g$

[a]The case where all individuals are generalists ($A_L = 0$) is a special case of Type 1.

4.3 Convergence

For any of these cases, the transitional dynamics are very tractable. The following lemma establishes that we can take initial conditions to have the property that promised consumption to the old is a constant fraction of income, which will be useful in our next proposition.

Lemma 1 *For any* (c_t^3, μ_t), *consumption promised to the old in period* $t + 1$ *is a constant fraction of output in period* $t + 1$, *i.e.* $c_{t+1}^3 = \alpha Y_{t+1}$.

Proof. First note that using equation (12), equation (10) implies that

$$X_t = \mu_{t+1}\left[\phi + \frac{\theta\phi}{(1 - \theta)(1 + \beta + \beta^2)}\right].$$

Using (12) and the first equality in (10), we can also rewrite equation (15) as

$$
\begin{aligned}
c_{t+1}^3 &= \left(\frac{(1 - \theta)D^{1-\theta}}{\phi}\right)\mu_{t+1}^{-\theta}\left(\frac{\beta}{1 + \beta}\right)X_t \\
&= \left(\frac{(1 - \theta)D^{1-\theta}}{\phi}\right)\left[\phi + \frac{\theta\phi}{(1 - \theta)(1 + \beta + \beta^2)}\right]\left(\frac{\beta}{1 + \beta}\right)\mu_{t+1}^{1-\theta}.
\end{aligned}
$$

---

[9]This will not necessarily be the case in section 5, where we introduce turbulence.

Finally, using (9), it follows that $c_{t+1}^3 = \alpha Y_{t+1}$, where

$$\alpha = \left[1 + \frac{\theta}{(1-\theta)(1+\beta+\beta^2)} \right] \frac{\beta(1-\theta)}{1+\beta}. \tag{19}$$

∎

Proposition 4 *Given parameter values, every equilibrium path converges to a unique steady state. The logarithmic distance of output from its steady state level is reduced by fraction θ every period.*

Proof. Following Lemma 1, we can take $c_t^3 = \alpha Y_t$. Then equation (13) implies that

$$\mu_{t+1} = (1-\alpha)\Lambda Y_t. \tag{20}$$

It follows that $\mu_{t+1}/\hat{\mu} = Y_t/\hat{Y}$, where $\hat{x}$ indicates the steady state value of variable x. To solve for the steady state, we combine equations (20) and (9) to get $\hat{\mu} = (1-\alpha)\Lambda(D\hat{\mu})^{1-\theta}$. This implies

$$\hat{\mu} = ((1-\alpha)\Lambda)^{\frac{1}{\theta}} D^{\frac{1-\theta}{\theta}} \tag{21}$$

$$\hat{Y} = ((1-\alpha)\Lambda)^{\frac{1-\theta}{\theta}} D^{\frac{1-\theta}{\theta}} \tag{22}$$

where α (given by equation (19)), Λ (given by equation (14)), and D (given by equations (29)–(32) in Appendix A) are all functions of exogenous parameters. Finally, equation (9) implies that

$$\frac{Y_{t+1}}{\hat{Y}} = \left(\frac{\mu_{t+1}}{\hat{\mu}} \right)^{1-\theta} = \left(\frac{Y_t}{\hat{Y}} \right)^{1-\theta}.$$

∎

It is interesting to note that neither α nor Λ depend on any of the uncertainty parameters. It follows that the effect of uncertainty is fully captured by the constant D. We exploit this fact below to show that steady state output increases as signals become more informative.

4.4 Comparative Statics

We now establish two key results concerning the way in which output and human capital react to changes in the precision of signals.

Proposition 5 *Assume that the fraction of firms with high productivity ($\bar{\pi}$) and the fraction of firms with good signal (ρ) remain constant as the precision of signals (π_g and π_b) changes. Then steady state output is increasing in the precision of signals.*

Proof. See Appendix B.1. ■

This Proposition suggests that economies in which good firms are likely to remain good are more productive than economies where firms face a lot of uncertainty about their future profitability. Our theory conforms with the fact that Japan outpaced the U.S. economy prior to the 1980's as long as the extent of fundamental uncertainty was lower in Japan than in the U.S. during that episode. Although convincing evidence on the extent of uncertainty is not readily available, there is evidence that the Japanese economy featured more specific human capital than the U.S., which we now show is consistent with our model in type 1 economies.[10]

Proposition 6 *Assume that the fraction of firms with high productivity ($\bar{\pi}$) and the fraction of firms with good signal (ρ) remain constant as the precision of signals (π_g and π_b) changes. In Type 1 economies, where all high productivity firms hire generalists, the fraction of workers investing in specific human capital is increasing in the precision of the signal.*

Proof. See Appendix B.2. ■

Together, our last two Propositions suggest that prior to the emergence of turbulence, Japanese firms hired more specific human capital and were more productive on average than their U.S. counterparts because they faced less uncertainty. We will argue in the next section that what made Japan's economy more productive in the 1960's and 1970's is also responsible for its large downturn once hit by turbulence.

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[10]For example, Kawai (1999) argues that the prolong recession in Japan is due in large part to the prevalence of specific human capital which is hard to re-allocate.

It should be noted, however, that our last Proposition does not extend to other types of equilibria. In particular, increasing the precision of signals can move the economy from Type 3, where there are no generalists, to Type 2, where generalists only work in surprisingly good firms. In this case, the fraction of individuals with specific human capital decreases as signals become more precise.

5   The Impact of Turbulence

In order to study the impact of turbulence, we introduce an aggregate state which determines the accuracy of the signal and takes one of two values: $z \in \{P, N\}$. The environment described in Section 2 corresponds to the precise state P, while in the noisy state N signals are completely uninformative: the probability of a firm drawing high productivity is independent of the signal. To keep the fraction of high productivity firms ($\overline{\pi}$) unchanged, we set the probability of getting high productivity in the noisy state equal to $\overline{\pi}$ regardless of the signal. Accordingly, one can think of state N as a state of the world in which productivities are re-shuffled across firms while maintaining the same *ex-post* measure of firms with low and high productivity as in state P.

It should be noted that only Type 1 or Type 3 equilibria can emerge in an economy which expects to remain in state N. When signals are completely uninformative, we have $E_g = E_b = \overline{A}$. The conditions summarized in Table 1 imply that either $\overline{A} < \gamma A_H$ and a Type 1 equilibrium emerges, or $\overline{A} > \gamma A_H$ and we have a Type 3 equilibrium. However, we view Type 1 equilibria as a more plausible and interesting case. This is because type 3 equilibria can only occur if the productivity levels are close to one another and general human capital is sufficiently less productive than specific human capital, which means that heterogeneity across firms plays a very minor role in that case. Although we presents some results for Type 3 equilibria below, we will concentrate our analysis mainly on Type 1 equilibria. Also, since economies where all individuals have general human capital are immune to turbulence, we will rule out that special case in this section by assuming that $A_L > 0$.

In the rest of this section we study the effects of turbulence in our model economy.

Turbulence is defined in a natural way as a drop in the precision of signals. We study two forms of turbulence. The first one is an expected permanent change in the precision of signals, realized before the investment in human capital is made. As such, this experiment consists of a regime switch from tranquil to turbulent times. Our second experiment is an unexpected transitory turbulence shock, that is, signals are uninformative for a single period.

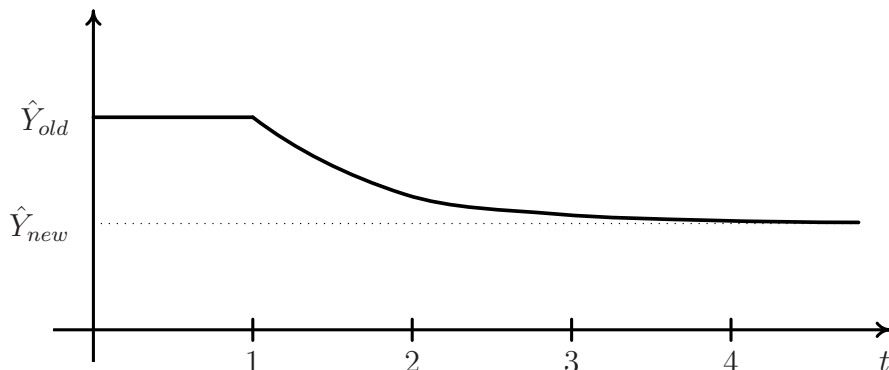## 5.1   Expected Permanent Change in Precision of Signals

Consider an economy which in period 0 is in steady state. In period 1, before any investment decisions have been made, everyone learns that from now on signals no longer contain any information. To determine the effects of this regime switch, we only need to determine how the steady state to which the economy will converge compares to the original steady state. Our convergence results from Section 4.3 implies that the economy will converge smoothly to this new steady state.

Proposition 7 *Following a permanent switch to a world in which signals are no longer informative (state N), the economy converges to a new steady state with lower output. The loss in output is increasing in the precision of signals in the original steady state.*

Proof. Recall that the transition to the new steady state is monotone (see Proposition 4). The proof then follows from Proposition 5, which establishes that the steady state value of output is increasing in the precision of signals. ∎

Figure 1 depicts the path of output following a regime switch from tranquil to turbulent times. The path for the number (measure) of firms (μ_t) mimics that of output. If the initial steady state is of Type 1, this Proposition implies that a regime switch has a larger impact in economies where specific human capital is predominant. We can interpret this result in light of the growing body of literature which points to the fact that the world economy has become more volatile and unpredictable in the last two decades (e.g. Ljungqvist and Sargent (1998, 2004)). The model is consistent with the fact that Japan, whose labor force is predominantly firm-specific, suffered a

Figure 1: Expected regime switch ($\theta = 2/3$)

much larger decline in output than the U.S. In the model, the adjustment to the ratio of specific to general human capital for the young adjusts immediately and remains at that new, lower level throughout the transition. The impact of turbulence thus depends in a crucial way on the amount of fundamental uncertainty prior to the regime switch.

5.2   Unexpected Turbulence Shock

In the last section we established that an expected regime switch from tranquil to turbulent times sends the economy on a smooth path towards a lower steady state. In this section we demonstrate that a transient turbulence shock can cause a prolonged period of low output. More importantly, we show that the fewer specialists a Type 1 economy has in the period of the shock, the more resilient it is to transient turbulence shocks. We first establish the intuitive result that output falls in the period of the shock, whether the (unexpected) shock is transitory or permanent.

Proposition 8 *An unexpected turbulence shock (transitory or permanent) leads to an immediate decrease in output relative to tranquil times, even though the fraction of firms with high productivity remains constant.*

Proof. First, consider an "informed" economy in which the number of entering firms μ_T is the same as in our economy just before the shock, but the shock is foreseen.

Since investment in and the allocation of human capital in the "informed" economy is efficient, the output in that economy in the period of turbulence is greater than in the economy that was surprised: $Y_T^I \geqslant Y_T^N$.

Second, output in the artificial "informed" economy is smaller than that of the undisturbed economy: $Y_T^I < Y_T^P$. To see this, note that, given μ_T, output is pinned down by the constant D (equation (9)). In the proof of Proposition 5 (see Appendix B.1), we established that D is strictly increasing in the precision of signals. And since the undisturbed economy has more precise signals than the "informed" one (due to the nature of the turbulence shock), it will produce strictly greater output from the same number of firms. It follows that $Y_T^N < Y_T^P$. ■

Our next Proposition establishes, for Type 1 and Type 3 economies, that the size of the fall is increasing in the precision of signals in tranquil times.

Proposition 9 *Assume that the fraction of firms with high productivity ($\overline{\pi}$) and the fraction of firms with good signal (ρ) remain constant as the precision of signals (π_g and π_b) changes. If the economy is initially in a Type 1 or Type 3 equilibrium, then the fraction of output lost following an unexpected transitory turbulence shock is increasing in the precision of signals in tranquil times.*

Proof. See Appendix B.3. ■

Observe that this proposition states that the proportional decrease in output is relative to where the economy would have been without turbulence, not relative to where the economy was last period. In other words, the result holds whether the economy is in or out of steady state prior to the shock.

This Proposition establishes that economies that are initially more productive (see Proposition 5) are also more vulnerable to turbulence shocks. The force that makes economies more productive (specific human capital) is also at the heart of their vulnerability to turbulence, as specific human capital cannot be re-allocated *ex-post*. Note that while this result only involves the intensive margin for Type 3 equilibria, it involves both the intensive and extensive margins for Type 1 equilibria since low uncertainty prior to the shock is conducive to the accumulation of specific human capital in such economies.

In order to determine the path of the economy following a transitory turbulence shock, we need to establish that in the model with aggregate uncertainty and complete markets, resources in both states are allocated in the same proportions between the young, middle-aged and old individuals. We establish this result by modeling an unexpected turbulent state, and making sure that the equilibrium allocation is the limit of equilibrium allocations of a general model with aggregate uncertainty as the probability of the turbulent state goes to zero. We then use this result to allocate resources following an unexpected one-time shock in an economy without aggregate uncertainty, thereby characterizing the entire path following the shock.

Let δ denote the probability of the aggregate state $z = P$ and let $q_t(z)$ denote the price in period t of an Arrow security that pays one unit of consumption good in period $t + 1$ contingent on the aggregate state being z. Finally, let $Y_t^d = Y_t - c_t^3$ denote the disposable income of middle-aged workers in period t.

Proposition 10 *The fractions of total output allocated to old and middle-aged workers are the same in all states:*
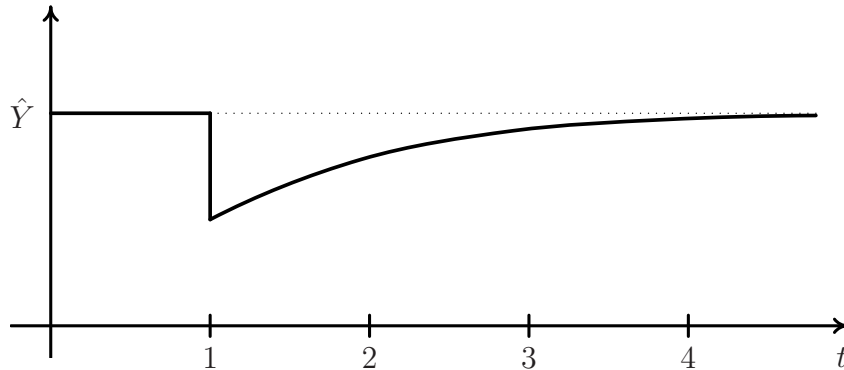
$$\frac{c_t^3(P)}{Y_t^d(P)} = \frac{c_t^3(N)}{Y_t^d(N)}.$$

Proof. See Appendix B.4. ∎

To summarize, Proposition 9 establishes the extent of the initial downturn in the economy. Proposition 10 establishes how resources are distributed among individuals of different ages in the period of the shock, thereby determining the initial conditions for the subsequent convergence which is described in Proposition 4. Figure 2 illustrates the path of output following a transitory turbulence shock.

Notice that in the period of the shock, human capital used in production is fixed from the previous period. Furthermore, since the environment in the period of the shock is the same as it was prior to the shock (other than the measure of firms), entering firms will make the same decisions in terms of human capital investments as before. Therefore the fraction of individuals with specific and general human in the period of the shock and throughout the transition path remains the same as it was prior to the shock. The lower output in the period of the shock is due to the misallocation of labor across firms in that period. The persistence of the shock is due

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Figure 2: Unexpected one-time shock $(\theta = 2/3)$

to the fact that lower output translates into a lower measure of firms entering, and so on.

Taken together, the results of this section imply that whereas economies characterized by low volatility tend to have more specific human capital and higher output, they also tend to be more vulnerable to turbulence shocks, which cause prolonged periods of low output. To the extent that the Japanese economy featured less uncertainty than the U.S. economy prior to the rise in economic volatility, the model is consistent with Japan going through a prolonged stagnation which was absent in the U.S.

6   Conclusion

This paper shows that the interaction of institutions and shocks can confront the fact that Japan outperformed the U.S. prior to the 1980's and has been suffering a prolonged economic downturn since the 1990's, which was largely avoided in the U.S. Our theory is that the economic environment in Japan in the post WWII era featured low volatility. In such an environment, efficiency dictates training the work force predominantly with specific human capital. In order to alleviate the insurance and hold-up problems necessary to sustain this type of work force, institutions need to

be established in order for firms and workers to agree to long term labor contracts.[11]

In our model, these institutions are on the one hand implicitly responsible for the fact that economies with lower uncertainty tend to have more specific human capital as well as higher output. On the other hand, the same institutions are responsible for the lack of reallocation in turbulent times, which causes output to fall for a prolong period of time.

An important caveat of this paper is that convincing evidence to the effect that fundamental uncertainty in Japan was lower than in the U.S. is hard to find. An obvious starting point could be to investigate the persistence of profits over time in different economies. Such measures, however, are highly problematic. In particular, our model does not imply that profits are more volatile in turbulent times relative to tranquil times.[12] The reason is that the composition of the labor force changes in such a way as to mitigate the impact of uncertainty. As an extreme case, our model implies that economies in which the labor force is predominately composed of generalists are largely immune to turbulence. We view the fact that Japan's labor force has much more specific human capital than the U.S. as evidence that uncertainty was lower in Japan than the U.S. prior to the recent turbulent episode.

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[11]It is well known that while Japan's unemployment protection is essentially absent, employment protection or security is very strong. For example, The OECD Job Study concludes for Japan that "... profit-maximization considerations, especially for large firms, involve both strong disincentives for employees to change jobs during prime age but also a commitment by these firms to provide employment security." See The OECD Job Study (1994), chapters 6 and 8.

[12]Indeed, Odagiri and Yamawaki (1986) present mixed evidence on the persistent of profits in the U.S. versus Japan.

A Equilibria: Details

Since all types of equilibrium are very similar, we only present in details how to construct an equilibrium for one of these cases. For the other cases, we only present the value of the constant D, which is sufficient to construct an equilibrium as shown in Section 4.

A.1 Type 1: All High Productivity Firms Hire Generalists

A.1.1 Middle-Aged Firms' Problems

There are four (4) types of middle-aged firms: firms who received a good signal when young can either have a high or low productivity level, and similarly for firms who received a bad signal.

Good Signal ($s = g$), High Productivity ($A = A_H$) Firms who received a good signal when young decided to hire and train $H(g)$ individuals in specific human capital. Their problem when middle-aged is as follows:

$$R(A_H, H(g)) \equiv \max_{G \geq 0} \left\{ A_H(H(g) + \gamma G)^\theta - w^G G \right\},$$

where w^G is the wage rate of generalists and G is the number of generalists to be hired. Optimality implies that

$$w^G = \theta A_H \gamma (H(g) + \gamma G)^{\theta - 1}, \tag{23}$$

and the number of generalists to hire is given by[13]

$$G(g) = \frac{1}{\gamma} \left[\left(\frac{\gamma \theta A_H}{w^G} \right)^{\frac{1}{1-\theta}} - H(g) \right]. \tag{24}$$

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[13]Since firms with low productivity do not hire generalists, it should be clear that $G(g)$ denotes the number of generalists hired by firms who received a good signal (and a high productivity level).

The revenue function for these firms is therefore given by

$$R(A_H, H(g)) = A_H \left(\frac{\gamma \theta A_H}{w^G} \right)^{\frac{\theta}{1-\theta}} - \frac{w^G}{\gamma} \left[\left(\frac{\gamma \theta A_H}{w^G} \right)^{\frac{1}{1-\theta}} - H(g) \right]$$

$$= (1-\theta) A_H \left(\frac{\gamma \theta A_H}{w^G} \right)^{\frac{\theta}{1-\theta}} + \frac{w^G}{\gamma} H(g).$$

Good Signal ($s = g$), Low Productivity ($A = A_L$)   Although these firms have a low realized productivity, they still received a good signal when young and thus also decided to hire and train $H(g)$ individuals. Since these firms will definitely not hire generalists (they would want to get rid of some of their specialists, so $G = 0$ for these firms), their revenue function when middle-aged is given by

$$R(A_L, H(g)) \equiv A_L H(g)^{\theta}.$$

Bad Signal ($s = b$), High Productivity ($A = A_H$)   Firms who received a bad signal when young decided to hire and train $H(b)$ individuals in specific human capital. Their problem when middle-aged is as follows:

$$R(A_H, H(b)) \equiv \max_{G \geq 0} \left\{ A_H (H(b) + \gamma G)^{\theta} - w^G G \right\}.$$

Optimality implies that

$$w^G = \theta A_H \gamma (H(b) + \gamma G)^{\theta - 1}, \tag{25}$$

and the number of generalists to hire in this case is given by[14]

$$G(b) = \frac{1}{\gamma} \left[\left(\frac{\gamma \theta A_H}{w^G} \right)^{\frac{1}{1-\theta}} - H(b) \right], \tag{26}$$

so their revenue function is given by

$$R(A_H, H(b)) = (1-\theta) A_H \left(\frac{\gamma \theta A_H}{w^G} \right)^{\frac{\theta}{1-\theta}} + \frac{w^G}{\gamma} H(b).$$

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[14]Since firms with low productivity do not hire generalists, it should be clear that $G(b)$ denotes the number of generalists hired by firms who received a bad signal (and a high productivity level).

Bad Signal ($s = b$), Low Productivity ($A = A_L$) These firms realized a low productivity after getting a bad signal, so they hired $H(b)$ specialists and will not hire any generalists ($G = 0$), so their revenue function when middle-aged is given by

$$R(A_L, H(b)) \equiv A_L H(b)^\theta.$$

From equations (23) and (25), we get the following relationship between high productivity firms' hiring decisions:

$$H(g) - H(b) = \gamma[G(b) - G(g)].$$

A.1.2   Young Firms' Problems

There are two types of young firms: those with a good signal and those with a bad signal. Both types of firm need to make a hiring decision when young based on their expected profits when middle-aged.

Good signal ($s = g$) The problem for firms who receive a good signal is as follows:

$$\max_H \left\{ \pi_g R(A_H, H) + (1 - \pi_g)R(A_L, H) - w^H H \right\},$$

where w^H is the wage rate per unit of firm specific human capital. Optimality thus requires that

$$w^H = \pi_g \frac{w^G}{\gamma} + (1 - \pi_g)\theta A_L H^{\theta-1},$$

which means that

$$H(g) = \left(\frac{\gamma(1 - \pi_g)\theta A_L}{\gamma w^H - \pi_g w^G} \right)^{\frac{1}{1-\theta}}. \tag{27}$$

Bad signal ($s = b$) The problem for firms who receive a bad signal when young is as follows:

$$\max_H \left\{ \pi_b R(A_H, H)) + (1 - \pi_b)R(A_L, H) - w^H H \right\}.$$

Optimality thus requires that

$$w^H = \pi_b \frac{w^G}{\gamma} + (1 - \pi_b)\theta A_L H^{\theta-1},$$

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which means that

$$H(b) = \left(\frac{\gamma(1 - \pi_b)\theta A_L}{\gamma w^H - \pi_b w^G} \right)^{\frac{1}{1-\theta}}. \tag{28}$$

Notice that by replacing the expression for $H(g)$ (equation (27)) into the expression for $G(g)$ (equation (24)), we have

$$G(g) = \frac{(\gamma\theta)^{\frac{1}{1-\theta}}}{\gamma} \left[\left(\frac{A_H}{w^G} \right)^{\frac{1}{1-\theta}} - \left(\frac{(1 - \pi_g)A_L}{\gamma w^S - \pi_g w^G} \right)^{\frac{1}{1-\theta}} \right],$$

which is strictly positive if the following condition holds:[15]

$$\frac{A_H}{A_L} > \frac{1 - \pi_g}{\gamma - \pi_g},$$

that is, this type of equilibrium occurs if (i) high productivity firms are sufficiently more productive than low productivity firms, (ii) the probability of getting high productivity conditional on having received a good signal is sufficiently high, and (iii) if specific human capital is sufficiently more productive than general human capital. Another way to write the previous expression is as follows:

$$\gamma A_H > E[A|s = g] = E_g,$$

which simply says that the good productivity level is sufficiently high and sufficiently productive relative to expected productivity once a firm knows her signal.

Similarly, by replacing the expression for $H(b)$ (equation (28)) into the expression for $G(b)$ (equation (26)), we can see that $G(b)$ will be strictly positive if the following condition holds:[16]

$$\frac{A_H}{A_L} > \frac{1 - \pi_b}{\gamma - \pi_b},$$

which means that when this condition is not satisfied, there will be no generalists in equilibrium.

A.1.3   Labor Market Clearing Condition

The labor market clearing condition (see equation (5)) is that the total number of workers hired adds up to unity. Since a fraction ρ of firms, of which there are a total

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[15]This condition corresponds to equation (16) in the main text.
[16]This condition corresponds to equation (17) in the main text.

of μ, receive a good signal and hire $H(g)$ individuals, and similarly for firms who receive a bad signal, we have

$$1 - M = \mu\rho H(g) + \mu(1 - \rho)H(b).$$

Similarly, middle-aged firms with good signals who's productivity turns out to be high $(\rho\pi_g)$ hire $G(g)$ generalists, and similarly for firms with bad signals, so that (see equation (5))

$$M = \mu\rho\pi_g G(g) + \mu(1 - \rho)\pi_b G(b).$$

Our market clearing condition thus reads

$$\mu\rho\left(\frac{\gamma(1 - \pi_g)\theta A_L}{\gamma w^H - \pi_g w^G}\right)^{\frac{1}{1-\theta}} + \mu(1 - \rho)\left(\frac{\gamma(1 - \pi_b)\theta A_L}{\gamma w^H - \pi_b w^G}\right)^{\frac{1}{1-\theta}}$$

$$+ \mu\rho\pi_g\frac{1}{\gamma}\left[\left(\frac{\gamma\theta A_H}{w^G}\right)^{\frac{1}{1-\theta}} - \left(\frac{\gamma(1 - \pi_g)\theta A_L}{\gamma w^H - \pi_g w^G}\right)^{\frac{1}{1-\theta}}\right]$$

$$+ \mu(1 - \rho)\pi_b\frac{1}{\gamma}\left[\left(\frac{\gamma\theta A_H}{w^G}\right)^{\frac{1}{1-\theta}} - \left(\frac{\gamma(1 - \pi_b)\theta A_L}{\gamma w^H - \pi_b w^G}\right)^{\frac{1}{1-\theta}}\right] = 1,$$

which, since $w^S = w^G = w_t$, simplifies to

$$w_t = \theta(D\mu_t)^{1-\theta},$$

where D is defined by

$$D = \rho\left[\pi_g A_H (\gamma A_H)^{\frac{\theta}{1-\theta}} + (1 - \pi_g)A_L\left(\frac{\gamma(1 - \pi_g)A_L}{\gamma - \pi_g}\right)^{\frac{\theta}{1-\theta}}\right]$$

$$+ (1 - \rho)\left[\pi_b A_H (\gamma A_H)^{\frac{\theta}{1-\theta}} + (1 - \pi_b)A_L\left(\frac{\gamma(1 - \pi_b)A_L}{\gamma - \pi_b}\right)^{\frac{\theta}{1-\theta}}\right]. \quad (29)$$

A.2 Type 2: Only High Productivity Firms with Bad Signals Hire Generalists

The only difference with the previous section is that $G(g) = 0$. It follows that the constant D from the labor market clearing condition is now defined as

$$D = \rho E_g^{\frac{1}{1-\theta}} + (1 - \rho)\left[\pi_b A_H (\gamma A_H)^{\frac{\theta}{1-\theta}} + (1 - \pi_b)A_L\left(\frac{\gamma(1 - \pi_b)A_L}{\gamma - \pi_b}\right)^{\frac{\theta}{1-\theta}}\right]. \quad (30)$$

A.3 Type 3: All Individuals are Specialists

The only difference with the previous case is that $G(g) = G(b) = 0$. It follows that the constant D from the labor market clearing condition is now defined as

$$D = \rho E_g^{\frac{1}{1-\theta}} + (1-\rho)E_b^{\frac{1}{1-\theta}}. \tag{31}$$

A.4 Special Case of Type 1: All Individuals are Generalists

Finally, we have

$$D = \bar{\pi} \left(\gamma^\theta A_H\right)^{\frac{1}{1-\theta}} + (1-\bar{\pi})\left(\gamma^\theta A_L\right)^{\frac{1}{1-\theta}}, \tag{32}$$

Note that this expression simplifies further as $A_L = 0$ is a necessary condition for this type of equilibrium to occur.

B Proofs

The exercise in the following propositions is to increase π_g and decrease π_b, keeping ρ constant, so that the fraction of firms with high productivity, $\bar{\pi} = \rho\pi_g + (1-\rho)\pi_b$, is unchanged. That is, $\pi_b = \frac{\bar{\pi} - \rho\pi_g}{1-\rho}$. The nature of the exercise allows us to employ the following result:

Lemma 2 *If f is strictly convex and $\pi_b = \frac{\bar{\pi} - \rho\pi_g}{1-\rho}$, then the function $\rho f(\pi_g) + (1-\rho)f(\pi_b)$ is increasing in π_g whenever $\pi_g > \pi_b$.*

Proof. The proof follows by simply replacing the formula for π_b into the function and taking the derivative. ∎

B.1 Proof of Proposition 5

We need to show that the value of D is strictly increasing in the precision of the signals (see equation (22)). We have three cases to consider, depending on the type of equilibrium under consideration.

Type 1: All firms with high productivity hire extra general human capital. This is the case when $E_g < \gamma A_H$. Note that this implies $\gamma > \pi_g \geq \pi_b$. The formula for D is given by equation (29). Differentiating with respect to π_g and recalling that $\frac{d\pi_b}{d\pi_g} = -\frac{\rho}{1-\rho}$, we get

$$\frac{dD}{d\pi_g} = \frac{\rho\gamma^{\frac{\theta}{1-\theta}}A_L^{\frac{1}{1-\theta}}}{(1-\theta)}\left[\left(\frac{1-\pi_g}{\gamma-\pi_g}\right)^{\frac{\theta}{1-\theta}}\left(\theta\frac{1-\pi_g}{\gamma-\pi_g}-1\right)-\left(\frac{1-\pi_b}{\gamma-\pi_b}\right)^{\frac{\theta}{1-\theta}}\left(\theta\frac{1-\pi_b}{\gamma-\pi_b}-1\right)\right].$$

Define the functions $g(p) = \frac{1-p}{\gamma-p}$ and $f(p) = g(p)^{\frac{\theta}{1-\theta}}(\theta g(p) - 1)$ and note that $\frac{dD}{d\pi_g} = \frac{\rho\gamma^{\frac{\theta}{1-\theta}}A_L^{\frac{1}{1-\theta}}}{(1-\theta)}(f(\pi_g) - f(\pi_b))$. So, to show that the value of D is strictly increasing in the precision of the signals, we need to show that $f(\pi_g) - f(\pi_b) > 0$. This follows from the facts that $\pi_g > \pi_b$ and that f is strictly increasing on $[\pi_b, \pi_g]$. To establish the latter, recall that $\gamma > \pi_g$, which implies that f is differentiable on the relevant interval.

$$f'(p) = \frac{\theta}{1-\theta}g(p)^{\frac{\theta}{1-\theta}}\frac{(1-\gamma)^2}{(1-p)(\gamma-p)^2} > 0.$$

Type 2: Only firms with bad signals but high productivity hire extra general human capital. This is the case when $E_b < \gamma A_H \leqslant E_g$. Note that this implies $\frac{A_H}{A_L} > \frac{1-\pi_b}{\gamma-\pi_b}$. The formula for D is given by equation (30). Taking the derivative with respect to π_g and recalling that $\frac{dE_g}{d\pi_g} = A_H - A_L$, we get

$$\frac{dD}{d\pi_g} = \rho E_g^{\frac{\theta}{1-\theta}}\frac{A_H - A_L}{1-\theta} - \rho\gamma^{\frac{\theta}{1-\theta}}A_H^{\frac{1}{1-\theta}} - \frac{\rho\gamma^{\frac{\theta}{1-\theta}}A_L^{\frac{1}{1-\theta}}}{1-\theta}\left(\frac{1-\pi_b}{\gamma-\pi_b}\right)^{\frac{\theta}{1-\theta}}\left(\theta\frac{1-\pi_b}{\gamma-\pi_b}-1\right).$$

Since $E_g \geqslant \gamma A_H$,

$$\frac{dD}{d\pi_g} \geqslant \frac{\rho\gamma^{\frac{\theta}{1-\theta}}A_L^{\frac{1}{1-\theta}}}{1-\theta}\left[\left(\frac{A_H}{A_L}\right)^{\frac{\theta}{1-\theta}}\left(\theta\frac{A_H}{A_L}-1\right)-\left(\frac{1-\pi_b}{\gamma-\pi_b}\right)^{\frac{\theta}{1-\theta}}\left(\theta\frac{1-\pi_b}{\gamma-\pi_b}-1\right)\right].$$

Define the function $h(x) = x^{\frac{\theta}{1-\theta}}(\theta x - 1)$ and note that $\frac{dD}{d\pi_g} = \frac{\rho\gamma^{\frac{\theta}{1-\theta}}A_L^{\frac{1}{1-\theta}}}{1-\theta}\left(h\left(\frac{A_H}{A_L}\right)-h\left(\frac{1-\pi_b}{\gamma-\pi_b}\right)\right)$. So, to show that the value of D is strictly increasing in the precision of the signals, we need to show that $h\left(\frac{A_H}{A_L}\right)-h\left(\frac{1-\pi_b}{\gamma-\pi_b}\right) > 0$. This follows from the facts that $\frac{A_H}{A_L} > \frac{1-\pi_b}{\gamma-\pi_b}$ and that h is strictly increasing on $[1, +\infty)$:

$$h'(x) = \frac{\theta g(p)^{\frac{\theta}{1-\theta}}}{(1-\theta)p}(p - 1).$$

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Type 3: Everyone invests in specific human capital only. The formula for D is given by equation (31).

$$\frac{dD}{d\pi_g} = \frac{\rho(A_H - A_L)}{1 - \theta} \left(E_g^{\frac{\theta}{1-\theta}} - E_b^{\frac{\theta}{1-\theta}} \right) > 0.$$

B.2   Proof of Proposition 6

We will show that the ratio of the stocks of specific and general human capital $\frac{\mathcal{H}}{\mathcal{G}} = \frac{\rho H(g) + (1-\rho)H(b)}{\rho \pi_g G(g) + (1-\rho)\pi_b G(b)}$ is increasing in the precision of the signal. Please refer to Appendix A.1 for derivations of underlying formulae.

When all high productivity firms hire generalists, equations (27) and (28) apply, and the total stock of specific human capital is given by

$$\mathcal{H} = \left(\frac{\gamma \theta A_L}{w} \right)^{\frac{1}{1-\theta}} \left(\rho \left(\frac{1 - \pi_g}{\gamma - \pi_g} \right)^{\frac{1}{1-\theta}} + (1 - \rho) \left(\frac{1 - \pi_b}{\gamma - \pi_b} \right)^{\frac{1}{1-\theta}} \right)$$

Using equations (24) and (26), we get the total stock of general human capital:

$$\mathcal{G} = \frac{1}{\gamma} \left[\phi \left(\frac{\gamma \theta A_H}{w} \right)^{\frac{1}{1-\theta}} - \left(\frac{\gamma \theta A_L}{w} \right)^{\frac{1}{1-\theta}} \left(\rho \pi_g \left(\frac{1 - \pi_g}{\gamma - \pi_g} \right)^{\frac{1}{1-\theta}} + (1 - \rho)\pi_b \left(\frac{1 - \pi_b}{\gamma - \pi_b} \right)^{\frac{1}{1-\theta}} \right) \right]$$

Taking the ratio,

$$\frac{\mathcal{H}}{\mathcal{G}} = \frac{\gamma A_L^{\frac{1}{1-\theta}} \left(\rho \left(\frac{1-\pi_g}{\gamma - \pi_g} \right)^{\frac{1}{1-\theta}} + (1 - \rho) \left(\frac{1-\pi_b}{\gamma - \pi_b} \right)^{\frac{1}{1-\theta}} \right)}{\phi A_H^{\frac{1}{1-\theta}} - A_L^{\frac{1}{1-\theta}} \left[\left(\rho \pi_g \left(\frac{1-\pi_g}{\gamma - \pi_g} \right)^{\frac{1}{1-\theta}} + (1 - \rho)\pi_b \left(\frac{1-\pi_b}{\gamma - \pi_b} \right)^{\frac{1}{1-\theta}} \right) \right]}$$

Define the following functions: $f(x) = \left(\frac{1-x}{\gamma - x} \right)^{\frac{1}{1-\theta}}$ and $g(x) = x f(x)$. Both functions are strictly convex on $(-\infty, \gamma)$. Applying Lemma 2, we conclude that the numerator of the ratio is increasing and the denominator of the ratio is decreasing in π_g. Thus, the ratio of specialists to generalists is increasing in the precision of the signal in the case when all high productivity firms hire generalists.

B.3 Proof of Proposition 9

Initial equilibrium is Type 1

Consider two economies, A and B, both of type 1, with the same fraction of firms receiving signal g and the same fraction of firms receiving productivity A_H. Assume that precision of the signals is higher in economy A. That is $\pi_g^A > \pi_g^B$ and $\pi_b^A < \pi_b^B$. We need to show that the proportional drop in output following an unexpected turbulence shock is greater in economy A than in economy B. We know from Proposition 5 that output in tranquil times is higher in economy A. We will show that output following an unexpected turbulence shock is lower in economy A, which implies that the fall is greater in economy A.

Consider additionally the "informed" economy I (see the proof of Proposition 8), where agents knew that the signals were uninformative ahead of time (and allocated investment and labor accordingly). Note that economy I is also of type 1, and we can apply equations (27) and (28) to show $\frac{H_g^A}{H_b^A} > \frac{H_g^B}{H_b^B} > \frac{H_g^I}{H_b^I} = 1$, where H_s^E is the total amount of specific human capital in firms with signals s in economy E. Further, Proposition 6 implies that $\mathcal{H}^A > \mathcal{H}^B > \mathcal{H}^I$ and $\mathcal{G}^A < \mathcal{G}^B < \mathcal{G}^I$, where $\mathcal{H}$ and $\mathcal{G}$ are the total stocks of specific and general human capital respectively. By construction, the allocation of investment and labor is optimal in economy I. This implies that both misallocation of investment (specific vs general) and misallocation of labor (H_g vs H_b) are greater in economy A than in economy B. We now simply need to show that

1. Given any allocation of investment, output is decreasing in misallocation of labor.

2. Given any (proportional) allocation of labor, output is decreasing in misallocation of investment.

Step 1: Given $\mathcal{G}$ and $\mathcal{H}$, output following the unexpected turbulence shock is decreasing in the misallocation of labor $\frac{H_g}{H_b}$. The exercise is to increase H_g while keeping $\mathcal{H}$ constant (this implies $H_b = \frac{\mathcal{H} - \mu\rho H_g}{\mu(1-\rho)}$). Since the number of high productivity firms

which had bad signal is higher than expected, we have to consider two cases:

1. All high productivity firms hire generalists.

2. Only high productivity firms which had bad signal hire generalists.

Case 1: Output per firm following the shock is

$$\frac{Y^N}{\mu} = \overline{\pi}\rho A_H(H_g + G_g^N)^\theta + \overline{\pi}(1-\rho)A_H(H_b + G_b^N)^\theta$$

$$+ (1-\overline{\pi})\rho A_L H_g^\theta + (1-\overline{\pi})(1-\rho)A_L H_b^\theta \quad (33)$$

Note that in this case all high productivity firms employ the same amount of human capital $L = H_g + G_g^N = H_b + G_b^N$. Further, since $\overline{\pi}\mu L = \overline{\pi}\mathcal{H} + \mathcal{G}$ and both $\mathcal{H}$ and $\mathcal{G}$ are fixed, the value of L is independent from the extent of misallocation of labor. Hence, we only need to consider the last two terms in (33), and Lemma 2 guarantees that output following the unexpected turbulence shock is decreasing in misallocation of labor.

Case 2: Output per firm following the shock is

$$\frac{Y^N}{\mu} = \overline{\pi}\rho A_H H_g^\theta + \overline{\pi}(1-\rho)A_H(H_b + G_b^N)^\theta + (1-\overline{\pi})\rho A_L H_g^\theta + (1-\overline{\pi})(1-\rho)A_L H_b^\theta \quad (34)$$

Simply taking derivative with respect to H_g (recalling that $\frac{dH_b}{dH_g} = \frac{-\rho}{1-\rho}$) confirms that output is decreasing in misallocation of labor.

Step 2: Keeping $\frac{H_g}{H_b}$ constant, output following the unexpected turbulence shock is decreasing in misallocation of investment. We will establish that output per firm following the shock is concave in $\mathcal{G}$ (keeping $\mathcal{G} + \mathcal{H}$ constant). Since economy B has too few generalists, and economy A has even fewer, this implies that economy A will produce less output than economy B following the shock (even if it had the same $\frac{H_g}{H_b}$ as economy B).

We need to consider the same two cases as in Step 1. Differentiating equations (33) and (34) twice with respect to $\mathcal{G}$ establishes the desired concavity in both cases.

B.3.1 Initial equilibrium is Type 3

The amount of output produced in the 'precise' state is

$$Y^P = D^{1-\theta}\mu^{1-\theta},$$

where $D = \rho E_g^{\frac{1}{1-\theta}} + (1-\rho)E_b^{\frac{1}{1-\theta}}$. If, unexpectedly, signals become completely uninformative *ex-post*, then total output produced is

$$Y^N = \frac{\mu^{1-\theta}}{D^\theta}(\overline{\pi}A_H + (1-\overline{\pi})A_L)\left(\rho E_g^{\frac{\theta}{1-\theta}} + (1-\rho)E_b^{\frac{\theta}{1-\theta}}\right).$$

The proportional decrease in output in the period of an unexpected "noise shock" is

$$\frac{Y^P - Y^N}{Y^N} = \rho(1-\rho)\frac{(A_H - A_L)(\pi_g - \pi_b)}{\overline{\pi}A_H + (1-\overline{\pi})A_L} \cdot \frac{E_g^{\frac{\theta}{1-\theta}} - E_b^{\frac{\theta}{1-\theta}}}{\rho E_g^{\frac{\theta}{1-\theta}} + (1-\rho)E_b^{\frac{\theta}{1-\theta}}}. \tag{35}$$

Differentiating equation (35) with respect to π_g shows that both fractions are increasing in π_g. Accordingly, the extent of damage (decrease in output) is greater in economies with higher expected precision of signals. Intuitively, a higher expected precision of signals increases output in the precise state (Y^P) and decreases output in the non-precise state (Y^N), thus making the extent of damage greater in economies with higher expected precision. Note that this result implies that $\frac{Y^P - Y^N}{Y^P}$ is also increasing in the precision of signals.

B.4 Proof of Proposition 10

Utility maximization by middle-aged workers implies the following state-contingent savings:

$$q_{t-1}(P)c_t^3(P) = \frac{\delta\beta}{1+\beta}Y_{t-1}^d,$$
$$q_{t-1}(N)c_t^3(N) = \frac{(1-\delta)\beta}{1+\beta}Y_{t-1}^d,$$

so that

$$\frac{c_t^3(P)}{c_t^3(N)} = \frac{\delta}{1-\delta}\frac{q_{t-1}(N)}{q_{t-1}(P)}. \tag{36}$$

Similarly, utility maximization of young workers in period $t-1$ implies that

$$q_{t-1}(P)Y_t^d(P) = \frac{(\beta + \beta^2)\delta}{1 + \beta + \beta^2}W_{t-1},$$

$$q_{t-1}(N)Y_t^d(N) = \frac{(\beta + \beta^2)(1 - \delta)}{1 + \beta + \beta^2}W_{t-1},$$

where W_t denotes the present value of lifetime income of young individuals born in period t. It follows that

$$\frac{Y_t^d(P)}{Y_t^d(N)} = \frac{\delta}{1 - \delta}\frac{q_{t-1}(N)}{q_{t-1}(P)}. \tag{37}$$

The statement of the Proposition follows from equations (36) and (37).

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