The Impact of a Disruptive Technology Change on Asset Prices

Natalia Gershun

Pace University

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Abstract

We examine the impact of a disruptive revolutionary technology change, which renders a large portion of the installed capital obsolete, on aggregate asset prices. Investors rationally expect compensation for bearing the risk of capital devaluation due to a disruptive technology change. In otherwise standard general equilibrium production model, the introduction of the possibility of such an event helps to resolve the equity premium and risk-free rate puzzles.

Key words: general equilibrium; asset pricing; peso problems
JEL classification: E23; E32; G12

Introduction

Major technological changes lead to significant changes in economies and businesses. Modern economic history records at least three profound technological changes: Use machines in manufacturing during the First Industrial Revolution, electrification and automation, the internet, and currently robotics, artificial intelligence, and ubiquitous reliance on data science, are examples of technological changes that permeate and alter all aspects of production and render a large portion of accumulated productive capital, including human capital, obsolete. It is natural to expect that these technological revolutions impact asset markets, which reflect anticipation of future growth, in a significant way long before the actual disruptive technology is widely used and its impact on existing productive assets becomes apparent. The interaction between technological waves and asset prices at the aggregate level at the onset of new techno-economic regimes is the focus of this paper.

Our basic premise is that once investors fully appreciate the effect of major technological innovations, they devalue the capital stock inherited from the previous technological regime since it is poorly suited to new economic conditions. Such devaluations render a portion of the existing capital stock effectively worthless. Since new technology adoption is costly, firms are not flexible in upgrading their capital stock to keep up on the technology frontier. Many established firms lose the race for technological dominance and, as a consequence, their value falls dramatically. We explore the possibility that equity prices reflect risks associated with the probable arrival of a new technological regime and the mere expectation of some unprecedented technological shock to the installed productive capital has a major impact on equity returns.

Data seem to support the hypothesis of capital depreciation (devaluation) at the start of a new technological regime. For example, Hobjin and Jovanovic (2001) report a three-fold decline in the market-cap/GDP ratio in 1973-4. In fact in 1973-74 the value of the securities in the U.S. market fell below the replacement cost of plant and equipment. They show that around 1974, the ratio of market value of incumbent firms to GDP declined by more than 50% and never recovered to its pre-1974 level, while the value of the market relative to GDP has tripled over the same period. Greenwood and Jovanovic (1999) suggest that in 1974 the U.S. economy first became aware of a techno-economic regime switch based on an anticipated information technology (IT) revolution. At that time the implications of the IT revolution for incumbent firms with large investments in old technology had become clear. The effect of the IT revolution on productivity was eventually highly favorable, but in 1974 the firms best suited to exploit modern technology did not exist.

In this paper, we model the impact of major technological changes on asset prices in the context of a dynamic stochastic general equilibrium model with production. In addition to the regular total factor productivity shocks, we introduce disruptive shocks to technology with a small ex-ante probability into our model. Since the arrival of major technological change results in a substantial depreciation of the existing capital stock, investors with equity holdings in incumbent firms view techno-economic regime shifts as catastrophic events. Tsai and Wachter (2015) provide a comprehensive literature survey of disaster models. Our model differs from those surveyed in that we apply the disaster modelling framework to major technological changes.

Historically, revolutionary technological changes are rare and it is impossible for financial markets to accurately assess their probability from available data. We explicitly introduce the mismatch between the frequency of major technological changes and their ex-ante assessed probability, which investors take into account when setting market prices. This feature gives rise to a peso problem in our model. If investors rationally anticipate the potential risk of a disruptive technological change, they require to be compensated for bearing this risk by a higher expected return even if this event has not occurred. Conditional on a return series, ex-post equity returns are higher in a sample, containing a lower frequency of such an event than is rationally expected by the market. Consequently, a seemingly high in-sample return on equity and equity risk premium may be rationally explained by the existence of a technology-related peso phenomenon.

Peso problems have been used to explain various situations where there is a small positive probability of an important event and investors take this probability into account when setting market prices (see Evans (1996) for a review of literature). The main critique of the peso argument as an explanation for the equity premium puzzle, exemplified by Campbell (1999), highlights two difficulties with the plausibility of the peso solution. On the one hand, the peso explanation for the equity premium requires not only a potential catastrophe but one, which affects stock market investors more seriously than investors in short-term debt instruments. On the other hand, the robustness of the equity premium across countries requires investors in all countries to be concerned about catastrophes. In addition, Longstaff and Piazzesi (2004) and Julliard and Ghosh (2012) among others, argue that if calibrated to the U.S. historical evidence, disaster models cannot match the level of realized equity premium with reasonable risk aversions if disaster shocks are defined as shocks to consumption. The novel feature of our approach is to define a disaster state as a state where agents in the economy become aware of a major technological development, realize the implications of this development for the incumbent firms and effectively depreciate a large portion of the existing capital stock. We think that our definition of the "catastrophic event" as a disruptive major change in technology satisfies both of Campbell's requirements and, in peso samples, allows our model to replicate the equity premium, observed in the U.S. data, without resorting to implausibly high levels of risk aversion

We consider the samples, where the described event actually occurs, and "peso" samples. In the peso samples investors rationally assign a very small positive probability to the arrival of a large-scale technological change, but the event does not materialize within the sample. We find that the samples with actually experienced disruptive technological change provide a good description of the financial statistics: the equity premium reaches about a third of the premium estimated in the U.S. data and the volatility of the asset returns from the model closely approximates the volatility of the returns on financial assets in the data. However, the model does not replicate the macroeconomic facts observed in the data: the volatility of output, consumption and especially capital is much higher than data suggest. By contrast, in our peso samples the macroeconomic description of the economy remains satisfactory and yet the model replicates the realized equity premium, although not the volatility of asset returns. These results are achieved for moderate levels of risk aversion and without any other departures from the classical asset pricing framework. In our base case (coefficient of the relative risk aversion equal to 3) the model generates a 5.31% equity premium.

Our paper is also related to the literature on the asset pricing implication of technological growth. Pastor and Veronesi (2009) focus on explaining “bubbles” in stock prices at the onset of technological revolutions, Gârleanu, Panageas, and Yu (2012) study the asset pricing implications of technological growth with both small productivity shocks and large innovations.

Gârleanu, Kogan, and Panageas (2012) explore a growth model with overlapping generations and find that innovation increases the competitive pressure of existing firms and a lack of intergenerational risk sharing introduces a new source of systematic risk in the economy, called displacement risk Lin, Palazzo and Yang (2019) study the impact of technology adoption on asset prices in a dynamic model that features a stochastic technology frontier. In equilibrium, firms operating with old capital are riskier because costly technology adoption restricts their ability to upgrade to the latest technology, making them more exposed to technology frontier shocks.

The remainder of the paper is organized as follows. Section 2 presents the model. Section 3 explains the numerical solution of the models, solves for stock prices and explains the calibration process. Section 4 investigates the model's quantitative results for asset prices and provides the macroeconomic summary of the model economy as a robustness check. Section 5 concludes.

1. The DSGE Model with a Disruptive Technological Change

To study the effect of a large-scale technology change on the macroeconomic and financial characteristics of the economy, we construct a general equilibrium model with a growing production sector. We consider an economy populated by an infinite number of identical households of measure μ with $\mu = 1$. These households are simultaneously consumers, workers and investors and maximize their expected life-time utility over consumption and leisure by choosing the fraction of time they wish to work and their asset holdings:

$$\max_{\{z^e_{t+1}, z^b_{t+1}, n^h_t\}} E\left\{\sum_{t=0}^{\infty} \beta^t \, U\left(c_t, 1 - n^h_t\right)\right\}$$

subject to the budget constraint

$$c_t + p^e_t z^e_{t+1} + p^b_t z^b_{t+1} \leq (p^e_t + d_t) z^e_t + z^b_t + w_t n^h_t \qquad (1)$$

In problem (1), z^e_t and z^b_t represent the fraction of the single equity share and the number of risk-free bonds held by the household in period t. The risk-free asset is a one-period bond which pays one unit of consumption at maturity in every state. Prices of the equity security and the risk-free assets are given by p_t^e and p_t^b respectively. Dividends, received by households in period t, are denoted by d_t. The fraction of time devoted to work is denoted by n_t^h and the competitively determined wage rate by w_t. β is the subjective discount factor and c_t is per capita consumption. The period preference ordering of the representative household is assumed to be of the standard CES form:

$$U\left(c_t, 1 - n_t^h\right) = \frac{\left((c_t)^\gamma \left(1 - n_t^h\right)^{1-\gamma}\right)^{1-\delta}}{1-\delta} \tag{2}$$

On the production side, there is a representative firm, which acts competitively. The firm begins period t with the capital stock k_t, inherited from the previous period. The capital stock evolves according to

$$k_{t+1} = \{(1-\theta)k_t + i_i\}\varphi_{t+1} \tag{3}$$

In equation (3), i_i stands for investment in the new capital, made in period t and θ – for the normal depreciation rate. Occasionally, agents in the economy learn of major technological developments. They expect that after the arrival of the new technology, the existing capital stock will be partially replaced with new productive assets. Upon this realization, the portion of the installed capital, including the last period's investment, becomes obsolete. Under this interpretation, φ_{t+1} represents a fraction of existing capital stock still considered valuable for production after a major change in technology. It is equal to 1 if there is no disruptive technological change in period $t+1$. If the new technology does arrive in period $t+1$, $\varphi_{t+1} = \varphi$, which is positive but less than 1.

The firm produces output y_t, using the standard constant returns to scale production technology, described by:

$$y_t = f\left(k_t, n_t^f\right) = \lambda_t (k_t)^\alpha \left(n_t^f\right)^{1-\alpha} \tag{4}$$

In equation (4), λ_t denoted total factor productivity in period t and α denotes the share of capital. After observing the shock to productivity, the firm hires labor n_t^f, taking the equilibrium wage rate as given. The residual output left after investing in new capital and paying for its labor, is distributed as dividends:

$$d_t = y_t - w_t n_t^f - i_t \tag{5}$$

Claims to dividends of the firm are traded in the stock market. The objective of the firm is to maximize its pre-dividend stock market value period by period:

$$\max_{\{n_t^f, i_i\}} (d_t + p_t^e)$$

subject to constraints given by (3), (4), (5), and

$$p_t^e = E\left(\sum_{j=1}^{\infty} \beta^j m_{t+j} d_{t+j}\right) \tag{6}$$

where m_{t+j} is a representative household's marginal rate of substitution in consumption between periods t and $t+j$, which also depends on leisure because of the non-separability of consumption and leisure in the preferences of the representative household:

$$m_{t+j} = \frac{U_c\left(c_{t+j}, 1-n_{t+j}^h\right)}{U_c\left(c_t, 1-n_t^h\right)} = \frac{\left(c_{t+j}\right)^{(1-\delta)\gamma-1}\left(1-n_{t+j}^h\right)^{(1-\delta)(1-\gamma)}}{(c_t)^{(1-\delta)\gamma-1}\left(1-n_t^h\right)^{(1-\delta)(1-\gamma)}} \tag{7}$$

The state of the economy in period t is characterized by the capital stock k_t, the shock to the total factor productivity λ_t, and by the shock to the accumulated capital stock, φ_t. Let vector $\tilde{s}_t = \{\tilde{\lambda}_t, \tilde{\varphi}_t\}$ denote the vector of exogenous state variables. The value function $V^h(k_t, \tilde{s}_t)$ represents a solution to the normalized stationary problem (1) starting from some initial conditions. The value function must satisfy:

$$V^h(k, \tilde{s}) = \max_{\{z^e, z^b, n^h\}} \{U(c, 1-n^h) + \beta \int V^h(k', \tilde{s}') dG(\tilde{s}, \tilde{s}')\} \tag{8}$$

subject to the budget constraint, described in problem (1). At all times the above expectation in (8) is computed using the conditional shock distribution $dG(\tilde{s}, \tilde{s}')$. The first order conditions for the representative household's equity and risk-free bond holdings define the financial asset prices:

$$p_t^e = \beta \int m_{t,t+1}(p_{t+1}^e + d_{t+1}) dG(\tilde{s}_t, \tilde{s}_{t+1}) \tag{9}$$

$$p_t^b = \beta \int m_{t,t+1} dG(\tilde{s}_t, \tilde{s}_{t+1}) \tag{10}$$

The first order condition for the labor decision defines the competitive wage rate:

$$w_t = \frac{(1-\gamma)c_t}{\gamma(1-n_t^h)} \tag{11}$$

The firm's optimization problem (6) results in an equivalent recursive formulation:

$$V^f(k,\tilde{s}) = \max_{\{i,n^f\}}\left\{m_{t,t+1}(\lambda f(k,n^f) - wn^f - i) + \beta \int V^f(k',\tilde{s}')dG(\tilde{s},\tilde{s}')\right\} \tag{12}$$

subject to constraint (3). The necessary and sufficient conditions for the firm's problem are its optimal labor hiring decision and the Euler equation, describing its optimal investment choice:

$$(1-\alpha)f_n\left(k_t,n_t^f\right) = w_t \tag{13}$$

$$-1 + E_t\left\{\beta m_{t,t+1}\left(f_k\left(k_{t+1},n_{t+1}^f\right)\lambda_{t+1} + 1 - \theta\right)\varphi_{t+1}\right\} = 0 \tag{14}$$

Equilibrium in this economy is a wage function $w_t = w(k_t,\tilde{s}_t)$, a share price function $p_t^e = p^e(k_t,\tilde{s}_t)$ and a risk-free bond price function $p_t^b = p^b(k_t,\tilde{s}_t)$ the first order conditions of the representative household (9) – (11) and the firm (13) and (14) are simultaneously satisfied, along with the market clearing conditions:

$$n_t^f = \int_0^1 n_t^h d\mu = n_t^h = n_t \tag{15}$$

$$z_t^e = \int_0^1 z_t^e d\mu = 1 \tag{16}$$

$$z_t^b = \int_0^1 z_t^b d\mu = 0 \tag{17}$$

2. Solution Method

We solve the model using the standard non-linear value function iteration technique. We allow conditional distribution of all shock processes to follow a finite-state discrete Markov chain as is commonly accepted in the dynamic equilibrium literature. We approximate continuous shock processes with a coarse state partition of two carefully chosen states for the shock to total factor productivity, $\lambda_t = \{\lambda_1,\lambda_2\}$. Likewise, the shock to the capital stock, brought up by the arrival of the disruptive new technology φ, can take on two values. It is equal to 1 if there is no change in technology and equal to φ if there is: $\varphi_t = \{1,\varphi\}$.

We end up with four possible states of exogenous uncertainty described below by the transition matrix M:

$$M = \begin{array}{cc} & \begin{array}{cccc} (\lambda_1,1) & (\lambda_2,1) & (\lambda_1,\varphi) & (\lambda_2,\varphi) \end{array} \\ & \left[\begin{array}{cccc} x-\upsilon_{1,3} & \tau-\upsilon_{1,4} & \upsilon_{1,3} & \upsilon_{1,4} \\ \tau-\upsilon_{2,3} & x-\upsilon_{2,4} & \upsilon_{2,3} & \upsilon_{2,4} \\ \varsigma-\upsilon_{3,3} & \psi-\upsilon_{3,4} & \upsilon_{3,3} & \upsilon_{3,4} \\ \psi-\upsilon_{4,3} & \varsigma-\upsilon_{4,4} & \upsilon_{4,3} & \upsilon_{4,4} \end{array}\right] \begin{array}{c} (\lambda_1,1) \\ (\lambda_2,1) \\ (\lambda_1,\varphi) \\ (\lambda_2,\varphi) \end{array} \end{array} \qquad (18)$$

States 3 and 4 are states where capital devaluation is experienced. They could be interpreted as "disaster states." The transition matrix M is assumed to be the true objectively and subjectively anticipated Markov process for this economy. Parameters $\upsilon_{ij}, j = 3, 4$ determine the likelihood of entering a disaster state j from state $i, i = 1,2,3,4$ while parameters $\upsilon_{jj}, j = 3, 4$ define the average number of periods, remaining in a disaster state. Given the specification of the parameter vector $\phi = \{E[\lambda], E[\varphi], \sigma_\lambda, \sigma_\varphi, \rho_{\lambda,\lambda'}, \rho_{\varphi,\varphi'}, \rho_{\lambda,\varphi}\}$, we can express each of these quantities in terms of the unknowns, $\{x, \tau, \varsigma, \psi, \upsilon_{1,3}, \upsilon_{1,4}, \upsilon_{2,3}, \upsilon_{2,4}, \upsilon_{3,3}, \upsilon_{3,4}, \upsilon_{4,3}, \upsilon_{4,4}\}$. Together with the requirements that probabilities in each row of M sum up to 1, these equations constitute a system of 11 equations and 12 unknowns, allowing us to regard one of the entries in M as a free parameter. This parameter can be varied until all entries of the matrix are positive and disaster states 3 and 4 are highly unlikely. If no such parameter can be found, this is evidence that the specifications of correlations between shocks are inconsistent.

2.1 Calibration

The model is simulated at quarterly frequencies. Following the previous dynamic equilibrium literature, we choose our parameter values as follows: The calibrated parameters include the capital's share of output α, chosen to equal 0.36; the quarterly capital depreciation rate is set at $\theta = 0.025$; the quarterly subjective discount factor β, is fixed at 0.99. For our benchmark parameterization, we choose the representative household's coefficient of intertemporal elasticity of substitution in consumption to be $\gamma = 3$ and the inverse of the Frisch elasticity of labor supply is $\delta = 3$ so that the steady state value of labor supply $\bar{n}$, is equal to one-third of the time endowment. All calibrated values are in line with empirical macro estimates and represent values commonly used in the literature, see for instance Boldrin, Christiano and Fisher (2001).

Motivated by Hall's (2001) estimate of the 1974 losses in the value of capital stock, we choose $\varphi = 0.5$ as our benchmark case.

The stationary probability of $\varphi = 0.5$ is set to be 1.34%. We set $\lambda_1 = 1.021$ and $\lambda_2 = 0.979$ to replicate the standard deviation of output, which in the U.S. is approximately equal to 1.81%. Table 1 summarizes parameterization of the baseline model. Sensitivity analysis for different values of φ and various stationary probabilities is presented in Tables 4 and 5.

Table 1 -- Parameter choices for the Baseline Model

Parameter	*Symbol*	*Value*
Capital share of output	α	0.36
Subjective discount factor	β	0.99
Capital depreciation rate	θ	0.025
Household's elasticity of intertemporal substitution in consumption	γ	3
Inverse of the Frisch elasticity of labor supply	δ	3
Total factor productivity process	λ	$\lambda_1 = 1.021$ $\lambda_2 = 0.979$
Share of capital devalued if the disruptive new technology arrives	φ	0.5
Stationary probability of the arrival of new technology		0.0136

2.2 Rates of Returns on Stocks and Bonds

Upon solving the model and obtaining the equilibrium share price function, we compute the time series of equity returns using the following definition:

$$R^e_{t,t+1}(k_t, \tilde{s}_t) = \frac{p^e_{t+1}(k_{t+1},\tilde{s}_{t+1}) + d_{t+1}(k_{t+1},\tilde{s}_{t+1})}{p^e_t(k_t,\tilde{s}_t)} \qquad (19)$$

Using the equilibrium bond price function, the period-by-period gross risk-free rate is computed as:

$$R^b_{t,t+1}(k_t, \tilde{s}_t) = \frac{1}{p^b_t(k_t,\tilde{s}_t)} \qquad (20)$$

Note that all asset prices are calculated using the conditional shock distribution $dG(\tilde{s}_t, \tilde{s}_{t+1})$, meaning that investors take into account the possibility of the arrival of the new technology when pricing assets.

2.3 Technology-Related Peso Effect

From historical records, we know that technological revolutions take place infrequently and unexpectedly. If a disruptive new technology arrives and takes hold, incumbent firms face adverse consequences: Their capital stock becomes obsolete and loses the significant part of its value. Investors rationally attach a positive probability to such events, which means that they view the matrix M in (18) as the true Markov process, objectively and subjectively anticipated, for this economy in their decision making. The probability that the capital depreciating technological change would be observed in any given period is very small and it is possible that disaster states may never materialize in the sample period under observation all the while the investors were rationally expecting these events to occur. We call such samples the "peso samples." In our numerical simulations we limit the length of the sample to 200 observations; this length corresponds to 50 years of quarterly observations. As a benchmark, we choose matrix M to fix a stationary probability of a capital destruction in the sample at 1.34%. With such parameterization, a major technological change is rationally expected to occur once in every 19 years and the probability of not encountering a disaster state in 50 years is 5%. See Appendix for derivation.

3. Quantitative Results

Table 2 presents a financial summary obtained from simulations of the model. Values in the second row of Table 2, which presents statistics from the variant of the model parameterization without disruptive technological changes ($\varphi = 1$), clearly exhibit the classic equity premium puzzle observed in Hansen (1985): A very high risk-free rate and a trivially small mean equity premium $E[\pi] = E[r^e] - E[r^b] = 0.02\%$. The volatility puzzle is present as well: The return on equity, the risk-free rate, and the equity premium are all too smooth when compared to their U.S. counterparts.

When capital devaluation is introduced into the model and it is observed with its anticipated relative frequency, the return on equity increases from 6.91% to 7.76%; the risk-free rate decreases from 6.89% to 5.71%. We are able to produce a 2.05% premium. Second moments are much improved as well: The volatility of the equity return increases to 11.68% and the volatilities of the risk-free rate and the equity premium become 3.42% and 11.96% respectively.

These values closely approximate their empirical counterparts. The economy, with realized disruptive changes in technology is a “high aggregate risk economy.” Investors facing higher consumption uncertainty are insuring themselves by buying risk-free assets. The increased demand for the safe assets drives down their returns. The equity security is the asset directly affected by capital destruction. It is less desirable for consumption-smoothing purposes and commands a higher return.

The corresponding financial statistics from the peso samples are different: The return on the equity security increases further to 8.22%, and the risk free rate drops to 2.91%. These two changes together give rise to a 5.31% equity premium. The volatilities of asset returns, however is low vis-à-vis their empirical counterparts. Cecchetti et al. (1998) propose a way to increase the second moments of the asset returns distribution in a similar setting without jeopardizing the realistic equity premium. Letting the transition matrix *M* in (18) exhibit stochastic variation would allow matching standard deviations of returns.

Table 2. Selected Financial Statistics

	Mean Values			Standard Deviations			Correlations with growth rate of output	
	$E[r^e]$	$E[r^b]$	$E[\pi]$	σ_e	σ_b	σ_π	$\rho_{r^e,\Delta y}$	$\rho_{r^e,\Delta y}$
U.S. Economy	7.77	1.07	6.70	16.54	2.3	16.76		
Capital devaluation is not anticipated and not present in the data	6.91	6.89	0.02	1.26	0.89	1.00	0.35	0.03
Capital devaluation is anticipated and present in the data	7.76	5.71	2.05	11.68	3.42	11.96	0.58	0.14
Capital devaluation is anticipated but not present in the data (“peso samples)	8.22	2.91	5.31	1.5	1.33	1.13	0.32	0.03

Note: We base the models’ statistics on 500 samples of 200 observations each. The standard deviation of output (GDP) is 1.81%. The model is parametrized using parameter values summarized in Table 1. We report financial statistics in annualized percentage terms. We obtain U.S. data on equity returns, Treasury bill returns, and consumer price index from the CRSP.

As a robustness check, we examine macroeconomic properties of our model for specifications outlined in rows two through four of Table 2. Table 3 presents macroeconomic statistics obtained from simulations of three variants of our model. For purposes of comparison, row one contains statistics derived from the U.S. data. Rows two through four present the average statistics for a complete set of 500 samples of 200 quarterly observations each. In all simulations, we normalize shocks to produce standard deviation of output comparable to the standard deviation of output observed in the U.S. data (1.81%). In row two, we report results from the variant of the model with $\psi = 1$ (disaster states are not anticipated and not present in the data samples), driven by persistent technology shocks. In this case, the model replicates Hansen's (1985) indivisible labor economy, a standard benchmark in the real business cycle literature. Row three shows statistics for the stationary economy, where the disaster state actually occurs and is fully and rationally anticipated by the agents. Row four presents results for the peso samples, where capital devaluation is rationally anticipated by the agents but never materializes in the samples under observation.

The statistics in row three reveal that capital devaluation, actually experienced, makes the standard model economy ex-post substantially more variable. The effect of the φ shock on capital stock is especially dramatic since capital stock is directly affected by a disruptive technological change. Relative to the standard model without disaster states, output is twice as variable. When combined with slightly less variable investment, the increase in output variability results in more than a six-fold jump in the variability of consumption, which is three times its observed value. In summary, our results suggest that an introduction of a disruptive technological change substantially compromises the ability of the standard model to replicate macroeconomic behavior of the U.S. economy.

The last row of Table 3 demonstrates that the pure possibility of capital destruction has almost no effect on macroeconomic properties of our model. Therefore, the perceived possibility of capital devaluation does not in itself alter the ability of the standard model to explain the stylized facts of the business cycle.

Table 3: Selected Macro-Aggregate Moments

	Standard Deviations					Correlations with Output			
	σ_y	σ_c	σ_n	σ_i	σ_k	$\rho_{c,y}$	$\rho_{n,y}$	$\rho_{i,y}$	$\rho_{k,y}$
U.S. Economy	1.81	1.35	1.79	5.3	0.63	0.88	0.88	0.80	0.04
Capital devaluation is not anticipated and not present in the data	1.81	0.69	0.95	5.82	0.53	0.77	0.95	0.97	0.04
Capital devaluation is anticipated and present in the data	3.66	4.41	1.32	5.56	9.64	0.88	-0.13	0.52	0.75
Capital devaluation is anticipated but not present in the data ("peso samples")	1.82	0.73	0.97	6.03	0.58	0.72	0.93	0.96	0.05

Note: We base the models' statistics on 500 samples of 200 observations each. The standard deviation of output (GDP) is 1.81%. The model is parametrized using parameter values summarized in Table 1. We report macroeconomic statistics per quarter in percentage terms. We obtain U.S. data from Datastream.

To interpret the above results, we note that when the economy enters the actual capital devaluation state the return on the equity security is negative because a portion of the asset's value disappears. In a disaster state, output of the consumption good decreases as part of the capital used in production is depreciated. The capital depreciation states are the states where consumption is low. In these states, agents don't want to save because they expect higher consumption in the periods to come, given the positive probability of better shocks in the future and zero probability of worse shock realization. The marginal utility of consumption is very high in disaster states, and expected marginal utility of consumption in future periods is low. This fact translates into a low demand for the risk-free asset (as it is the main instrument for saving in disaster states) and the high risk-free rate. In the peso samples, we exclude capital depreciation states where the return on the equity security is the lowest and return on the risk-free security is the highest. Accordingly, the expected return on equity slightly rises and the expected risk-free rate is substantially reduced. The elimination of both the lowest tail of the equity return distribution and the highest tail of the risk-free return distribution from peso samples also accounts for the substantially lower standard deviation of returns to both securities.

Changing the Magnitude of Capital Destruction due to Change in Technology: The quantity φ represents the fraction of capital stock left in productive use after the arrival of a new disruptive technology; the larger the value of φ, the less severe the consequences of the technology change (see Table 4).

Table 4: Effect of Changes in the Magnitude of Capital Destruction

	Capital devaluation is anticipated and present in the sample			Capital devaluation is anticipated but present in the sample		
	$\varphi = 0.5$	$\varphi = 0.7$	$\varphi = 0.9$	$\varphi = 0.5$	$\varphi = 0.7$	$\varphi = 0.9$
Financial Statistics						
$E[r^e]$	7.76	7.14	6.91	8.22	7.64	7.13
$E[r^b]$	5.71	6.52	6.81	2.91	5.12	6.40
$E[\pi]$	2.05	0.62	0.10	5.31	2.52	0.73
σ_e	11.68	6.96	2.73	1.50	1.34	1.28
σ_b	3.42	1.88	1.11	1.33	1.03	0.94
σ_π	11.96	7.03	2.61	1.13	1.05	1.02
Standard Deviations						
Output	3.66	2.51	1.94	1.82	1.81	1.81
Consumption	4.41	2.45	1.06	0.73	0.73	0.71
Employment	1.32	1.06	0.97	0.97	0.95	0.95
Investment	5.56	5.56	5.81	6.03	5.88	5.83
Capital stock	9.64	5.04	1.62	0.58	0.55	0.53
Contemporaneous Correlations with Output						
Consumption	0.88	0.81	0.72	0.72	0.74	0.76
Employment	-0.13	0.33	0.85	0.93	0.93	0.94
Investment	0.52	0.70	0.93	0.96	0.97	0.97
Capital stock	0.75	0.60	0.29	0.05	0.05	0.04
Contemporaneous Correlations with Growth Rate of Output						
r^e	0.58	0.5	0.35	0.32	0.35	0.35
r^b	0.14	0.14	0.08	0.03	0.03	0.03

Note: We base the models' statistics on 500 samples of 200 observations each. In all cases presented in this table $\gamma = 3$ and $prob(\varphi \neq 1) = 1.34\%$.

In an actual disaster scenario, as the magnitude of the capital destruction, given by φ, increases, the volatility of the macro-series decreases. The effect is especially apparent for the capital stock. In the peso cases, the perceived magnitude of capital destruction has almost no effect on the real side of the economy. On the financial side, whether a disruptive technology change actually takes place or it is merely perceived by investors, asset returns are quite sensitive to modifications in the magnitude of the parameter φ: The return on equity decreases and the risk-free rate increases as the share of capital is in danger of obsoleteness because of switch in the techno-economic regime decreases. In the economy where destruction actually takes place, the risk-free rate climbs from 5.71% (if 50% of the capital stock is rendered obsolete) to 6.81% (if only 10% of the capital stock becomes unproductive). The premium shrinks from 2.05% to 0.1%. In the peso setting, the effect is similar, but the risk-free rate grows much faster. In the peso samples, the change in φ from 0.5 to 0.9 increases the risk-free rate from 2.91% to 6.4%. The results mean that the decrease in the magnitude of a disaster (experienced or perceived) makes the equity security more attractive; at the same time, the advantage to holding the risk-free asset diminishes.

Changing the Stationary Probability of a Disruptive Change in Technology: In the samples where capital depreciation is actually present, the volatility of macroeconomic aggregates increases rapidly with the increase in the likelihood of the disaster states (see Table 5). Capital and consumption are especially responsive to changes in this parameter. The increase in the macro uncertainty results in the upward movement of the equity return and the downward movement of the risk-free rate.

In the peso setting, changes in a perceived probability of the disaster have a negligible effect on the volatility of the macroeconomic variables. However, even small changes in the ex-ante stationary probability of a potential capital disruption have greater impact on the first moments of the financial returns in peso samples than in samples, where the technological disruption actually occurs. These findings can be explained in light of our earlier argument. The higher stationary probability of the arrival of the new technology implies that in samples where the frequency of realization of these events differs more from their ex ante assessed probability, a peso problem is exacerbated and the firm’s stock ex-post returns will be higher than in samples where the ex-post frequency of disruptive technology changes and their ex-ante probability are more closely aligned, ceteris paribus.

Table 5: Impact of Changes in the Stationary Probability of a Disruptive Technological Change

	Capital devaluation is anticipated and present in the sample			Capital devaluation is anticipated but present in the sample		
$Prob(\varphi \neq 1)$	0.44	1.34	1.74	0.44	1.34	1.74
Financial Statistics						
$E[r^e]$	7.19	7.76	7.98	7.36	8.22	8.58
$E[r^b]$	6.39	5.71	5.30	5.47	2.91	1.48
$E[\pi]$	0.8	2.05	2.68	1.89	5.31	7.10
σ_e	5.69	11.68	13.89	1.35	1.50	1.54
σ_b	1.95	3.42	4.20	1.05	1.33	1.30
σ_π	5.64	11.96	14.44	1.00	1.13	1.20
Standard Deviations						
Output	2.55	3.66	4.13	1.82	1.82	1.79
Consumption	2.30	4.41	5.20	0.72	0.73	0.76
Employment	1.12	1.32	1.40	0.98	0.97	0.93
Investment	5.86	5.56	5.36	5.99	6.03	5.86
Capital stock	4.51	9.64	11.47	0.54	0.58	0.57
Contemporaneous Correlations with Output						
Consumption	0.79	0.88	0.92	0.71	0.72	0.74
Employment	0.44	-0.13	-0.31	0.93	0.93	0.92
Investment	0.75	0.52	0.46	0.97	0.96	0.96
Capital stock	0.4	0.75	0.83	0.03	0.05	0.06
Contemporaneous Correlations with Growth Rate of Output						
r^e	0.42	0.58	0.62	0.29	0.32	0.31
r^b	0.07	0.14	0.23	-0.02	0.03	0.17

Note: We base the models' statistics on 500 samples of 200 observations each. In all cases presented in this table $\gamma = 3$ and $\varphi = 0.5$.

The risk-free rate is more sensitive to the increase in the ex-ante stationary probability of the disruptive technological change than the return on equity. An increase in the perceived probability of capital destruction from 0.44% to 1.74% drives down the risk-free rate from 5.47% to 1.48% producing the realistic 7.1% equity premium. The risk-free bond prices are not subject to the adverse consequences of the technological regime switch to the same extent as equity prices since in peso samples the fundamentals of the economy are not affected. The higher the probability of the major technology change, the higher the investors demand for safe assets for the consumption smoothing purposes.

4. Conclusion

In the context of a dynamic general equilibrium model with a growing production sector, we introduce the possibility of a technological regime switch from established to a disruptive new technology, which tends to dominate all aspects of production. The technological revolution leads to the obsoleteness of a significant portion of existing capital stock. When the market learns that a certain technology will become outdated, firms with expected earnings strongly dependent on the incumbent technology will experience a dramatic fall in their stock prices. Investors in the incumbent firms view these technology revolutions as a "catastrophic" or disaster states. Defined in this way, the disaster state has a potentially more profound impact on the aggregate behavior of asset prices in the model economy than a disaster state characterized by a low output realization. Rational investors require to be compensated for the possibility of a highly negative rate of return in the form of a relatively high return when this risk is not realized. This mechanism gives rise to the technology-based peso phenomenon in our model. Consequently, the technology-related modeling of a potential disaster state in our model has more pronounced implications for asset pricing without requiring the implausibly high levels of investors' risk aversion to produce higher return on equity, low risk-free rate and almost realistic equity premium.

We have shown that in the samples with the actually experienced capital depreciation, the first and the second moments of financial returns come close to their counterparts in the data; however, in these samples, the volatility of the macroeconomic aggregates is unrealistically high. By contrast, if capital devaluation is merely a possibility but is not observed in the sample data (i.e., the peso samples), our model adequately describes the basic facts of the observed business cycle. A perceived possibility of capital depreciation further reduces the mean risk-free rate, even relative to the actual capital devaluation scenarios, and slightly increases the equity return. As a result, in the model that contains no channel for shock amplification, such as indivisible labor, variable capital utilization, or adjustment costs, without any market imperfections or leverage, we are able to achieve a realistic equity premium of 5.31% in the benchmark case.

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