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Online Appendix

A Some Notable Changes in the U.S. Economy

In the past several decades, there have been some notable regulatory changes in the United States that have shaped the channels that we consider as potential drivers of declining business dynamism and rising market concentration. In this section, we briefly discuss these changes with a focus on the corporate tax rates, R&D subsidies, and entry costs (see Section 9 in the main text for the changes in the knowledge diffusion margin).

The U.S. tax system experienced two major overhauls in the 1980s, with the passage of the Economic Recovery Act of 1981 and the Tax Reform Act of 1986. Although the United States has notoriously sustained the highest statutory corporate income tax rates among the developed countries until recently, the Tax Reform Act actually decreased this rate substantially in 1986, as shown by the solid black line in Figure A.1. Moreover, despite high statutory rates, the effective tax rates that determine the actual corporate tax bill paid by firms are known to be much lower due to various tax benefits. According to the CBO estimates, the effective rate was about 19 percent in 2012, almost 20 percent below the statutory rate (Congressional Budget Office, 2017).[53] Indeed, the average effective rates were lower in the period after 1980 than the previous two

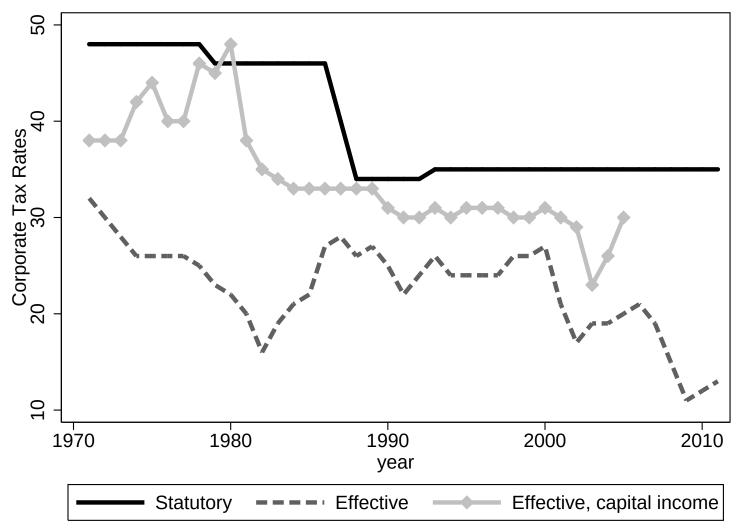

Figure A.1: Effective Corporate Tax Rate in the U.S.

Notes: Statutory tax rates are obtained from Internal Revenue Service Statistics of Income Historical Table 24 and show the value for the top bracket. Statutory tax rates have been at least the level shown in the graph for corporate income brackets above $75,000. The effective corporate tax rate is calculated as Tax Receipts on Corporate Income/(Corporate Profits After Tax [without IVA and CCAdj]+Federal Government's Tax Receipts on Corporate Income) using Federal Reserve Economic Data (U.S. Bureau of Economic Analysis, 2019). Effective corporate tax rates on capital income are taken from Congressional Research Service report RS21706 (Gravelle, 2004).

[53]For instance, while trucking companies paid 30 percent, biotech companies paid less than 5 percent of their income as tax in 2009 (Appelbaum, 2011). Furthermore, some companies such as General Electric not only did not pay any taxes but actually claimed positive tax benefits (Kocieniewski, 2011).

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decades and have fallen strongly after 2000 (dashed line). Finally, the effective corporate tax rate on capital income has declined as well, as depicted by the marked solid line.

Probably a less-known change has occurred in the R&D support provided by the U.S. government. In 1981, the government introduced a federal R&D tax credit for the first time. Starting in 1982 with Minnesota, several states followed suit by introducing their own state-level R&D tax credits. Figure A.2 summarizes these changes. The gray bar denotes the introduction of the federal tax credit, and the subsequent bars show the total number of U.S. states with a provision of R&D tax credits, along with their names. This substantial support for R&D boosted firms' investment in innovative activity (Akcigit et al., 2018), which is especially true for large established incumbents—the recipients of the bulk of R&D tax credit claims (Tyson and Linden, 2012)—given that firms need to generate taxable profits to claim the credit.[54] Figure A.2 also shows that there were significant changes in both R&D expenditure of firms and domestic innovative activity following these aggressive policy changes. Average R&D intensity of publicly traded U.S. firms showed a dramatic increase (solid line). Moreover, after an expected delay, the annual share of patents registered by U.S. residents in total patent applications increased as well (dashed line).

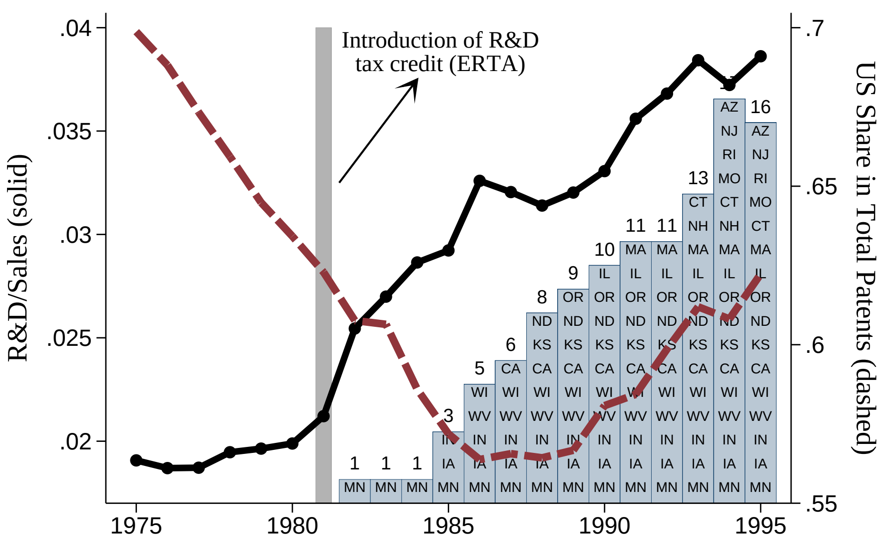

Figure A.2: Federal and State-Level R&D Tax Credits in the U.S.

Source: Akcigit et al. (2018).

Market economies are regulated to level the playing field for competing firms and encourage a more dynamic business environment. Yet too much regulation could slow the economy by simply distorting the incentives to invest and grow. "Overregulation" has become a growing concern among policy circles, especially with its potentially larger burden on small businesses (Crain and Crain, 2010; U.S. Chamber of Commerce Foundation, 2017). The detrimental effect of higher entry barriers, and regulations in particular, on business entry has also been documented

[54]In fact, the nonrefundability feature of the U.S. R&D tax credits is subject to major criticism, along with the lack of preferential rates for small firms, which contrasts with schemes in other major economies such as France and the United Kingdom (Congressional Budget Office, 2007; Tyson and Linden, 2012). These features are especially important for the efficiency of tax credits in supporting the innovative activity of highly dynamic small and young firms, which are usually the firms that are constrained by the high cost of R&D capital.

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by the academic literature (Klapper et al., 2006; Klapper and Love, 2010). In more recent work, Gutiérrez et al. (2019) stress the importance of higher entry costs in terms of the regulatory framework in driving the decline in business entry and competition.

The level of regulatory burden in the economy is hard to measure. However, the length of the *Federal Register*, where all new rules, executive orders, and other legal notices are published, gives a clue about how the regulatory burden has evolved in the United States. Figure A.3 plots the number of pages in the *Federal Register* over time. The increase in the amount of flow of new regulations lends some support to the argument that the regulatory burden on U.S. businesses has grown, which could reasonably be expected to have weighed on entrants and small businesses. In this sense, this regulatory shift could have had some detrimental impact on business dynamism. In light of this debate, we also investigate changes in the cost of entry in our quantitative analysis.

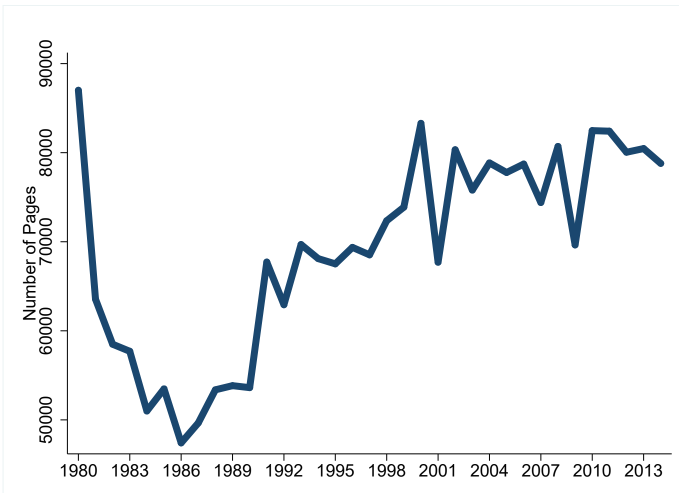

Figure A.3: Number of Pages in the U.S. *Federal Register*

Notes: Data were obtained from the Regulatory Studies Center.

B Additional Analytical Derivations

This section presents the derivation of some key objects of the analysis.

B.1 Evolution of μ_{mt}

The evolution of μ_{mt} in some special cases are as follows:

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$$\frac{\mu_{\bar{m}t+\Delta t}-\mu_{\bar{m}t}}{\Delta t}=x_{\bar{m}-1t}\mu_{\bar{m}-1t}-\left(x_{-\bar{m}t}+\tilde{x}_{-\bar{m}t}+\delta\right)\mu_{\bar{m}t} \tag{B.1}$$

$$\frac{\mu_{1t+\Delta t}-\mu_{1t}}{\Delta t}=\left(2x_{0t}+\tilde{x}_{0t}\right)\mu_{0t}+\left(\left(1-\phi\right)x_{-2t}+\left(1-\tilde{\phi}\right)\tilde{x}_{-2t}\right)\mu_{2t}-\left(x_{1t}+x_{-1t}+\tilde{x}_{-1t}+\delta\right)\mu_{1t} \tag{B.2}$$

$$\frac{\mu_{0t+\Delta t}-\mu_{0t}}{\Delta t}=\sum_{k=1}^{\bar{m}}\left(\phi_f x_{-kt}+\phi_e\tilde{x}_{-kt}+\delta\right)\mu_{kt}+\left(\left(1-\phi\right)x_{-1t}+\left(1-\tilde{\phi}\right)\tilde{x}_{-1t}\right)\mu_{1t}-\left(2x_{0t}+\tilde{x}_{0t}\right)\mu_{0t} \tag{B.3}$$

B.2 Welfare

In the model economy, aggregate welfare over horizon T calculated at time t_0 is given by

$$\mathbb{W}^c_{t_0}=\int_{t_0}^{t_0+T}\exp(-\rho\left(s-t\right))\log C_{cs}\,ds.$$

In Section 7, we report the difference in consumption-equivalent welfare between a counterfactual and the baseline economy using the following relationship:

$$\int_{t_0}^{t_0+T}\exp(-\rho\left(s-t_0\right))\log C^{new}_{cs}\,ds=\int_{t_0}^{t_0+T}\exp(-\rho\left(s-t_0\right))\log\left(\left(1+\varsigma\right)C^{base}_{cs}\right)\,ds. \tag{B.4}$$

If a parameter change generates a new income sequence C^{new}_{ct} between t_0 and t_0+T satisfying the above relationship, we say that the representative household in the counterfactual economy has a ς percent higher (lower) consumption-equivalent welfare over horizon T, with $\varsigma>0$ ($\varsigma<0$). In other words, when $\varsigma>0$ ($\varsigma<0$), the representative consumer in the baseline economy would need to receive ς percent higher (lower) income at each point in time between t_0 and t_0+T in order to obtain the same level of welfare as in the counterfactual scenario.

C Solution Algorithm

Before the discussion of the calibration results, a brief description of our solution algorithm is in order. The algorithm builds on the one developed by Akcigit et al. (2018), who construct an open-economy version of the model considered here. To find the transition path that emerges as the result of endogenous responses of firms to changes in parameters, we solve a discretized version of the system. The solution algorithm assumes that the economy is initially in the BGP and that the shocked parameter values converge to their new BGP value in T periods, where each period is divided into eight sub-periods. Notice that, due to the endogenous firm decisions and the resulting endogenous adjustments in aggregate variables, the convergence of the economy to the new BGP takes longer, which we assume to happen $T_{bgp}>T$ periods. The algorithm is an iterative backward solution method (see Acemoglu et al., 2016). The progression of the algorithm starts with solving for the terminal balanced growth path and then derives firm values and aggregate variables over the transition going backward from the terminal state. A summary of steps is as follows.

1. Start with a guess of parameter values.
2. Compute the initial balanced growth path, where time derivatives are zero by definition. Compute the innovation rates, the implied growth rates, and finally the interest rate compatible with balanced growth.
3. Compute the terminal balanced growth path in T_{bgp} defined by the terminal parameter values similarly.
4. Next calculate the equilibrium over the transition. Guess a time path for the interest rate with the terminal value set to its new BGP level. Solve for firm values and innovation rates backward in time starting from the terminal BGP.
5. Using the resulting sequences and starting from the initial gap distribution implied by the initial BGP, simulate forward the income path and its growth rate. Use the Euler equation to derive the implied interest rate sequence and compare it to the series fed initially.
6. Update the guess for the interest rate series with the implied one and restart from step 2 until the two converge. Once they do, use the final interest rate series and firm decisions to compute the moments of interest.
7. Compare model-based moments to data targets. Search over the parameter space until the following objective function (see Acemoglu et al., 2018) is minimized:

$$\sum_{k=1}^{N} \frac{|\text{model}(k) - \text{data}(k)|}{\frac{1}{2}|\text{model}(k)| + \frac{1}{2}|\text{data}(k)|},$$

   where k denotes each moments and N is the number of targets.

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D Additional Quantitative Results

Table D.1 presents the sensitivity of calibration moments to a 1 percent change in parameters. Figure D.4 displays the calibrated transition paths of s and τ.

Table D.1: Sensitivity Analysis: Responses to 1 Percent Change in Parameters

	R&D scale incumbent α	**R&D scale entrant** $\tilde{\alpha}$	**Step size** λ	**Knowledge diffusion** δ	**Drastic innov.** $\phi = \tilde{\phi}$	**Step size curvature** ψ	**CES param.** β
Growth	-0.39%	0.00%	1.40%	0.01%	0.01%	3.96%	1.20%
Entry	0.02%	-0.37%	0.00%	0.14%	0.00%	0.01%	-14.3%
R&D	-0.43%	0.01%	1.41%	-0.57%	-0.06%	4.35%	7.90%
Profit	-0.31%	0.03%	1.13%	-0.92%	-0.11%	3.56%	2.41%
Markup	-0.39%	0.02%	1.40%	-0.92%	-0.11%	4.52%	4.66%
Entry contr.	0.02%	0.53%	0.43%	0.82%	0.29%	-1.35%	-18.9%
Growth disp.	-0.09%	-0.06%	0.05%	0.25%	0.03%	-0.30%	-10.9%

Notes: Table entries show the elasticity of moments to each parameter. Precisely, they show the percentage change in each target in response to a 1 percent increase in each parameter, keeping the other parameters constant at their calibrated value.

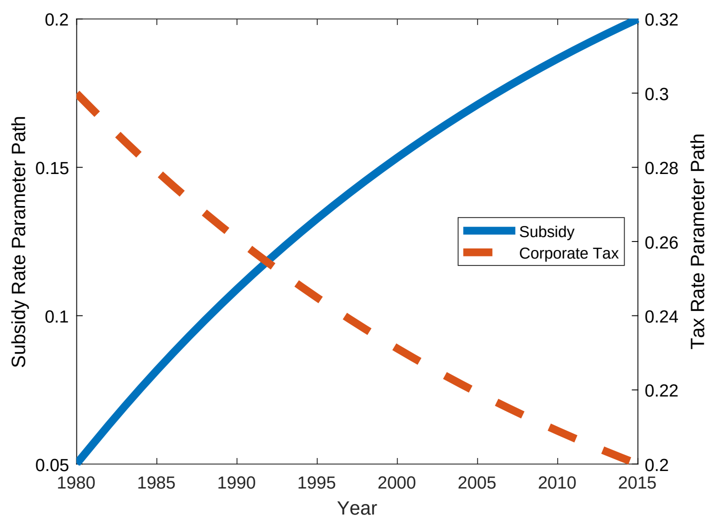

Figure D.4: Transition Paths of s and τ

E Implications Regarding Firm Age

While the age margin is not a particular focus of the analysis, the calibrated model displays remarkable success in replicating some salient age–related moments in the data. Figure E.5 shows the age distribution both in the model and in the data at two different points in time. In the data, the full range of the age distribution is available starting only from 2003. Therefore, Figure E.5a shows the distribution in 2003, and Figure E.5b shows it in 2015, the final period of the analysis. In Figure E.5a, we show the model-based distribution both in 2003 along the transition and at the initial BGP for comparison. The model's success is outstanding—except for some overshooting of old firms—given the parsimonious structure of the model and the fact that

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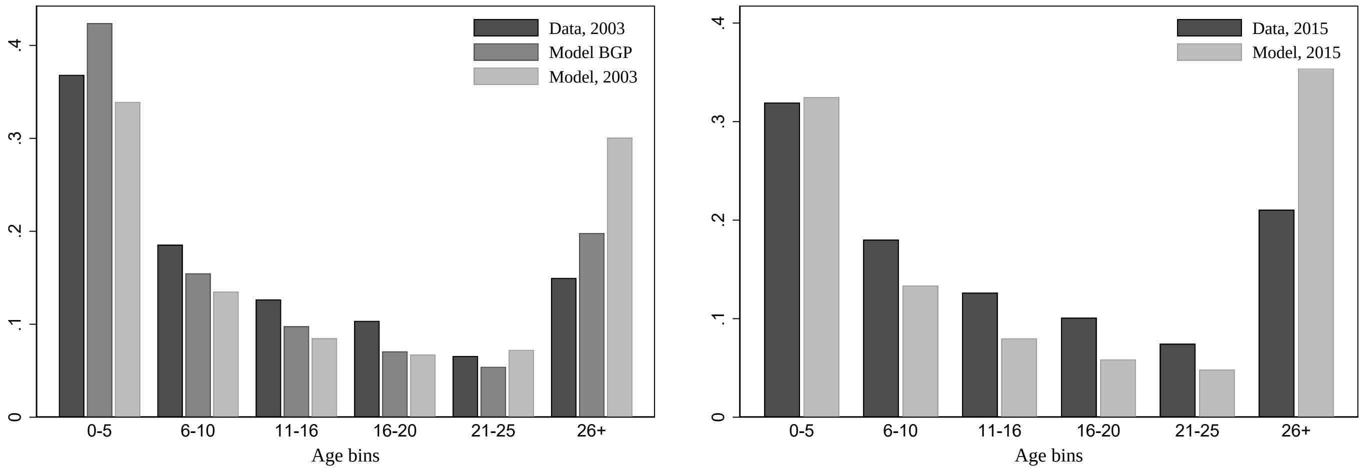
we provide no information to the calibration that is specific to the age distribution moments. The close link between the data and model persists in 2015 (Figure E.5b), with the model generating an average aging of the firms, again in lines with the data. These implications suggest that the model could reasonably speak to distinct margins of the data, even though our goal, and therefore, the model construction did not specifically focus on those margins.



A) Age distribution, 2003

B) Age distribution, 2015

Figure E.5: Age distribution

Notes: The data moments are the authors' own calculations from the BDS data.

The model's implications are strikingly close to the data also in terms of the exit rate by age bins in the data. Figure E.6 demonstrates this point based on three age categories. Solid lines represent the exit rates in the data, and dashed lines represent the counterparts in the model based on the simulated data over the transition. We observe that while the exit rate in the data is about stable for most age groups, it is visibly declining for the youngest firms. Indeed, for 1-year-old firms (not shown), the rate falls from close to 30 percent in the early 1980s to 20 percent by 2015.[55] Turning to the implications of the model, two observations stand out. First, in line with the data, there is a decline in the exit rate of the youngest firms. Second, the exit rate is relatively stable for a good portion of age bins over the transition, again in sync with the data. As such, the model is quite successful in replicating the empirical patterns of exit rates by firm age. Notice also that even the levels of exit rates are commensurate in the data and the model, especially for the youngest firms, including the decline in their exit rate.

To understand the exit dynamics in the model, notice that entrant firms replace followers and neck-and-neck firms, as opposed to entering the economy by increasing the measure of firms. This dynamic—entrants replacing incumbents—is typical of Schumpeterian creative destruction models. Consequently, any change in the rate of entry means a change in the rate of exit for some group of firms and age bins. In the analysis, it is especially the youngest firms that are subject to this churn, as they happen to be mostly followers. As a result, their exit rate falls steadily during the transition in lockstep with the decline in firm entry.

[55] A decline occurs also for 2- and 3-year-old firms, albeit to a smaller extent.

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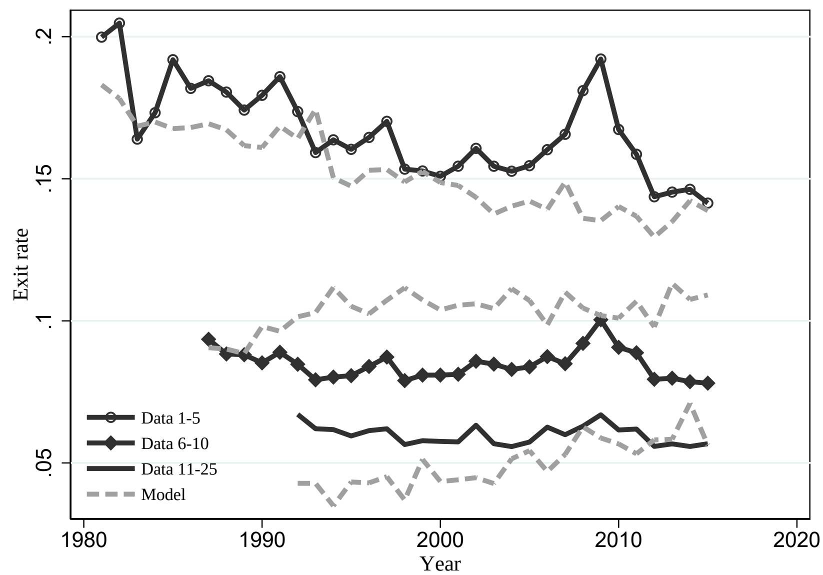

Figure E.6: Exit Rate by Age Bins in the Model

Notes: Solid lines represent the data and dashed lines represent the model-based simulations.

F The Model with Population Growth

This section presents the details of the model with population growth. To keep the exposition as clear as possible, we present a version in which the intermediate varieties are perfect substitutes, and the population growth is constant. Relaxing these assumptions would be a straightforward extension. We highlight the main differences from the baseline model without population growth and mention the parts that remain the same only briefly.

F.1 Preferences

Assume that the economy consists of a unit measure of representative households, each expanding at rate η, sharing total consumption cooperatively among the members and being fully altruistic about their dynasty (we assume the initial size of each household is normalized to one). In this environment, the representative household derives logarithmic utility from consumption:

$$U_t = \int_t^{\infty} \exp\left(-\hat{\rho}\left(s-t\right)\right) \ln \hat{C}_s \, ds,$$

where $\hat{C}_t$ represents consumption per capita (or member of the household) at time t, and $\hat{\rho} \equiv \rho - \eta > 0$ is the effective discount rate. The budget constraint of the representative household reads as

$$C_t + \frac{dA_t}{dt} = L_t w_t + r_t A_t + G_t,$$

where $L_t = \exp(\eta t)$ denotes total labor of the household (supplied inelastically), A_t denotes total assets, and G_t denotes lump-sum taxes levied or transfers distributed by the government.

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Normalizing by the size of the household, we can re-write this expression as

$$\hat{C}_t + \frac{d\hat{A}_t}{dt} = w_t + (r_t - \eta)\,\hat{A}_t + \hat{G}_t.$$

The prices and the choice of the numeraire are defined as in the baseline model.

F.2 Technology and Market Structure

Final Good. The final good, which is used for consumption, is produced in perfectly competitive markets according to the following production technology:

$$\ln Y_t = \int_0^1 \ln y_{jt}\, dj, \tag{F.5}$$

where y_{jt} denotes the amount of intermediate variety $j \in [0,1]$ used at time t. Each variety is produced by a monopolist, which we describe next.

Intermediate Goods and Innovation. As in the baseline model, incumbent firms produce with linear technology using labor and compete à la Bertrand. Therefore, the market structure remains the same. The mechanics of incumbent and entrant innovation follow Akcigit and Ates (2019), with one modification to R&D cost functions that ensures the existence of BGP. Let R_{ijt} denote the R&D expenditures of firm i in product line j at time t, h_{ijt} denote R&D workers, and x_{ijt} denote the resulting innovation arrival rate. We modify the cost function of the arrival rate x_{ijt} as follows:

$$R_{ijt} = e^{\eta t} \alpha \frac{x_{ijt}^{\gamma}}{\gamma} w_t,$$

where γ is the (inverse) elasticity of R&D with respect to R&D workers and w_t denotes the wage rate that prevails in the economy. As a result, the R&D production function is given by $x_{ijt} = \left(\gamma \frac{h_{ijt}}{\alpha e^{\eta t}}\right)^{\frac{1}{\gamma}}$. Similarly, the R&D cost function of the entrant reads as

$$\tilde{R}_{ijt} = e^{\eta t} \tilde{\alpha} \frac{\tilde{x}_{ijt}^{\tilde{\gamma}}}{\tilde{\gamma}} w_t.$$

This scaling ensures that the R&D cost increases in proportion to the population growth. This, in turn, prevents the R&D activity from becoming less and less costly (relative to revenues) and the equilibrium growth rate from becoming explosive.

F.3 Equilibrium

Next, we define the equilibrium relationships.

Households. Optimal household decisions determine the equilibrium interest rate of the economy. The Euler equation implies

$$r_t = g_t + \hat{\rho}, \tag{F.6}$$

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where g_t is the growth rate of output.

Final- and Intermediate-Good Production. The optimization of the representative final-good producer generates the following demand schedule for the intermediate good $j \in [0, 1]$:

$$y_{ijt} = \frac{Y_t}{p_{ijt}}, \tag{F.7}$$

where p_{ijt} is the price of intermediate good j that the monopolist producer i charges. The unit-elastic demand schedule implies that the final-good producer spends an equal amount Y_t on each intermediate good j.

Given the linear production function, an intermediate producer's marginal cost becomes

$$mc_{it} = \frac{w_t}{q_{it}}, \tag{F.8}$$

which increases in the wage rate and decreases in the firm's labor productivity.[56] Moreover, Bertrand competition leads to limit pricing such that the intermediate producer sets its price to the marginal cost of its competitor:

$$p_{it} = \frac{w_t}{q_{-it}}. \tag{F.9}$$

Then the optimal equilibrium quantities of the intermediate varieties produced are given as

$$y_{it} = \begin{cases} \frac{q_{-it}}{\omega_t} & \text{if} \quad q_{it} > q_{-it} \\ 0 & \text{if} \quad q_{it} < q_{-it} \end{cases}, \tag{F.10}$$

where $\omega_t \equiv w_t / Y_t$ denotes the normalized wage level. We assume that in neck-and-neck sectors, i.e., when $q_{it} = q_{-it}$, the production is assigned randomly to both firms. The optimal production employment of the intermediate producer follows as

$$l_{it} = \frac{y_{it}}{q_{it}} = \frac{1}{\omega_t \lambda^{m_{it}}} \quad \text{for} \quad m_{it} \geq 0. \tag{F.11}$$

The operating profits of the intermediate-good producer exclusive of R&D expenditures becomes

$$\pi(m_{it}) = (p_{it} - mc_{it})\, y_{it} = \left(1 - \frac{1}{\lambda^{m_{it}}}\right) Y_t \quad \text{for} \quad m_{it} \geq 0, \tag{F.12}$$

and $\pi(m_{it}) = 0$ otherwise. Similarly, the price-cost markup reads as

$$mk(m_{it}) = \frac{p_{it}}{mc_{it}} - 1 = \lambda^{m_{it}} - 1 \quad \text{for} \quad m_{it} \geq 0, \tag{F.13}$$

and $mk(m_{it}) = 0$ otherwise.

While the equilibrium relationships that define the static decisions resemble the ones in the

[56] We dropped the subscript j for brevity and will do so in the remainder of the discussion.

model without population growth, population growth indeed modifies some of these expressions to account for the ever-expanding workforce. To see that, define $\hat{Y}_t$ as the per capita output such that $Y_t = L_t\hat{Y}_t = \exp(\eta t)\hat{Y}_t$. Similarly, define the labor share of income $\hat{\omega}_t \equiv (w_t L_t)/Y_t = w_t/\hat{Y}_t$. Notice that this variable is stationary and remains constant in BGP—reciprocally, ω_t shrinks at rate η. Rewriting the above expressions, we obtain

$$y_{it} = \frac{q_{-it}}{w_t} Y_t = \frac{q_{-it}}{\omega_t} = q_{-it}\frac{e^{\eta}\hat{Y}_t}{w_t} = q_{-it}\frac{e^{\eta}}{\hat{\omega}_t}, \tag{F.14}$$

$$l_{it} = \frac{y_{it}}{q_{it}} = \frac{1}{\omega_t \lambda^{m_{it}}} = \frac{e^{\eta}}{\hat{\omega}_t \lambda^{m_{it}}}. \tag{F.15}$$

Therefore, unlike in the baseline model, the size of the firm (measured in terms of output or employment) expands in proportion to the population. The rate of expansion is common to all firms. As such, we already observe that while population growth brings about additional dynamics, it does not affect firm characteristics in relative terms and, therefore, does not interfere with key mechanisms—at least in static equilibrium. Next, we explore the dynamic decisions.

F.3.1 Firm Values and Innovation

Incumbents. The value function of a leader that is m steps ahead is given by

$$\begin{aligned} r_t V_{mt} - \dot{V}_{mt} = \max_{x_{mt}} \Bigg\{ & (1-\tau_t)\left(1 - \frac{1}{\lambda^m}\right) Y_t - (1-s_t)\, e^{\eta t}\alpha \frac{x_{mt}^{\gamma}}{\gamma} w_t + x_{mt}\left[V_{m+1t} - V_{mt}\right] \\ & + \left(\phi x_{-mt} + \tilde{\phi}\tilde{x}_{-mt} + \delta\right)\left[V_{0t} - V_{mt}\right] \\ & + \left((1-\phi)\, x_{-mt} + (1-\tilde{\phi})\,\tilde{x}_{-mt}\right)\left[V_{m-1t} - V_{mt}\right] \Bigg\}. \end{aligned} \tag{F.16}$$

Similarly, the value of an m-step follower is defined as

$$\begin{aligned} r_t V_{-mt} - \dot{V}_{-mt} = \max_{x_{-mt}} \Bigg\{ & -(1-s_t)\, e^{\eta t}\alpha \frac{x_{-mt}^{\gamma}}{\gamma} w_t + (1-\phi)\, x_{-mt}\left[V_{-m+1t} - V_{-mt}\right] \\ & + \left(\phi x_{-mt} + \delta\right)\left[V_{0t} - V_{-mt}\right] \\ & + x_{mt}\left[V_{-m-1t} - V_{-mt}\right] + \tilde{x}_{-mt}\left[0 - V_{-mt}\right] \Bigg\}. \end{aligned} \tag{F.17}$$

Finally, the value of a neck-and-neck incumbent is given by[57]

$$\begin{aligned} r_t V_{0t} - \dot{V}_{0t} = \max_{x_{0t}} \Bigg\{ & -(1-s_t)\, e^{\eta t}\alpha \frac{x_{0t}^{\gamma}}{\gamma} w_t + x_{0t}\left[V_{1t} - V_{0t}\right] \\ & + x_{-0t}\left[V_{-1t} - V_{0t}\right] + \frac{1}{2}\tilde{x}_{0t}\left[0 - V_{0t}\right] \Bigg\}. \end{aligned} \tag{F.18}$$

Notice the modified cost of R&D in all these equations.

Before we compute optimal innovation efforts, the following lemma defines the normalized firm values.

[57] Notice that, when there is successful entry, the neck-and-neck incumbent exits with a one-half probability because, by assumption, the entrant randomly replaces one of the two incumbents with the same technology.

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Lemma 2 *Define the normalized value v_{mt} such that $V_{mt} = v_{mt} Y_t$. Then, for $m > 0$, v_{mt} is given by*

$$\begin{aligned}\hat{\rho} v_{mt} - \dot{v}_{mt} = \max_{x_{mt}} \Bigg\{ & (1-\tau_t)\left(1 - \frac{1}{\lambda^m}\right) - (1-s_t)\,\alpha \frac{x_{mt}^{\gamma}}{\gamma} \hat{\omega}_t + x_{mt}\left[v_{m+1t} - v_{mt}\right] \\ & + \left(\phi x_{-mt} + \tilde{\phi} \tilde{x}_{-mt} + \delta\right)\left[v_{0t} - v_{mt}\right] \\ & + \left((1-\phi)\, x_{-mt} + (1-\tilde{\phi})\, \tilde{x}_{-mt}\right)\left[v_{m-1t} - v_{mt}\right] \Bigg\}.\end{aligned}$$

Normalized values for $m \leq 0$ are defined reciprocally.

The expression in the above lemma is identical to the one in the baseline model. This fact establishes that population growth as modeled here does not change the firm dynamics or the nature of competition in this model. For the sake of completeness, we describe the optimal innovation decisions of firms and some aggregate variables.

The first-order conditions of the problems defined earlier yield the following optimal innovation decisions:

$$x_{mt} = \begin{cases} \left[\frac{1}{\alpha \hat{\omega}_t (1-s_t)} \left(v_{m+1t} - v_{mt}\right)\right]^{\frac{1}{\gamma - 1}} & \text{if } \ m \geq 0 \\ \left[\frac{1}{\alpha \hat{\omega}_t (1-s_t)} \left\{(1-\phi)\, v_{m+1t} + \phi v_{0t} - v_{mt}\right\}\right]^{\frac{1}{\gamma - 1}} & \text{if } \ m < 0 \end{cases}. \tag{F.19}$$

Entrants. Recall that entry is directed at particular product lines, and a successful entrant replaces the follower (or one of the incumbents with an equal probability if entry is to a line in a neck-and-neck state). The problem of an entrant that aims for a product line with an m-step gap is given as

$$\max_{\tilde{x}_{-mt}} \left\{ -e^{\eta t} \tilde{\alpha} \frac{\tilde{x}_{-mt}^{\tilde{\gamma}}}{\tilde{\gamma}} w_t + \tilde{x}_{-mt}\left[(1-\tilde{\phi})\, V_{-m+1t} + \tilde{\phi} V_{0t} - 0\right] \right\}, \tag{F.20}$$

where $m > 0$.[58] The resulting optimal innovation decisions of entrants are specified as follows:

$$\tilde{x}_{mt} = \begin{cases} \left[\left(\tilde{\alpha} \hat{\omega}_t\right)^{-1} \left\{(1-\tilde{\phi})\, v_{m+1t} + \tilde{\phi} v_{0t}\right\}\right]^{\frac{1}{\tilde{\gamma}-1}} & \text{if } \ m < 0 \\ \left[\left(\tilde{\alpha} \hat{\omega}_t\right)^{-1} v_{1t}\right]^{\frac{1}{\tilde{\gamma}-1}} & \text{if } \ m = 0 \end{cases}. \tag{F.21}$$

We close the model by specifying aggregate wage and output. The final–good production function in equation (F.5) yields the wage rate as a function of Q_t and μ_{mt}:

$$w_t = Q_t \lambda^{-\sum_{k=0}^{\bar{m}} k \mu_{kt}}. \tag{F.22}$$

[58] The problem of an entrant aiming for a line in a neck-and-neck state is defined similarly, except that any innovation by the entrant improves on the follower only by one step:

$$\max_{\tilde{x}_{0t}} \left\{ -e^{\eta t} \tilde{\alpha} \frac{\tilde{x}_{0t}^{\tilde{\gamma}}}{\tilde{\gamma}} w_t + \tilde{x}_{0t}\left[V_{1t} - 0\right] \right\}.$$

Because there is no notion of a technology leader in a neck-and-neck state, there is no drastic entrant innovation that allows it to catch up with the technology frontier.

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The labor market clearing condition holds at all times, i.e.,

$$e^{\eta t} = \int_0^1 \left[l_{ijt} + l_{-ijt} + h_{ijt} + h_{-ijt} + \tilde{h}_{jt} \right] \, dj,$$

and implies the following normalized wage ω_t:

$$\omega_t = \left(\sum_{k=0}^{\bar{m}} \mu_{kt} \lambda^{-k} \right) \left[e^{\eta t} - \sum_{k=0}^{\bar{m}} e^{\eta t} \mu_{kt} \left(\frac{\alpha}{\gamma} \left(x_{kt}^{\gamma} + x_{-kt}^{\gamma} \right) + \frac{\tilde{\alpha}}{\tilde{\gamma}} \tilde{x}_{-kt}^{\tilde{\gamma}} \right) \right]^{-1} \Rightarrow$$

$$\omega_t e^{\eta t} = \left(\sum_{k=0}^{\bar{m}} \mu_{kt} \lambda^{-k} \right) \left[1 - \sum_{k=0}^{\bar{m}} \mu_{kt} \left(\frac{\alpha}{\gamma} \left(x_{kt}^{\gamma} + x_{-kt}^{\gamma} \right) + \frac{\tilde{\alpha}}{\tilde{\gamma}} \tilde{x}_{-kt}^{\tilde{\gamma}} \right) \right]^{-1} \equiv \hat{\omega}_t. \tag{F.23}$$

The last line makes clear that the expression for the aggregate labor share is the same as in the baseline model. Notice that the last expression uses the optimal R&D labor demand schedules

$$h_{ijt} = e^{\eta t} \frac{\alpha}{\gamma} x_{ijt}^{\gamma} \quad \text{and} \quad \tilde{h}_{jt} = e^{\eta t} \frac{\tilde{\alpha}}{\tilde{\gamma}} \tilde{x}_{jt}^{\tilde{\gamma}}. \tag{F.24}$$

Combining equations (F.22) and (F.23) gives the level of final output per capita:

$$\hat{Y}_t = Q_t \lambda^{-\sum_{k=0}^{\bar{m}} k \mu_{kt}} \hat{\omega}^{-1}. \tag{F.25}$$

Finally, we define the evolution of aggregate productivity and the gap size distribution, which jointly determine the dynamics of the model. The transition path of Q_t is determined by innovations of incumbent firms and entrants that enter neck-and-neck industries, which improve the productivity of workers employed in intermediate-good production:

$$\ln Q_{t+\Delta t} - \ln Q_t = \ln \lambda \left[\mu_{0t} \left(2x_{0t} + \tilde{x}_{0t} \right) + \sum_{k=1}^{\bar{m}} \mu_{kt} x_{kt} \right] \Delta t + o\left(\Delta t \right), \tag{F.26}$$

which also defines the aggregate growth rate in the balanced growth path (BGP). The transition of μ_{mt} for $\bar{m} > m > 1$ is as follows:

$$\begin{aligned} \frac{\mu_{mt+\Delta t} - \mu_{mt}}{\Delta t} = &+ x_{m-1t} \mu_{m-1t} + \left(\left(1 - \phi \right) x_{-m-1t} + \left(1 - \tilde{\phi} \right) \tilde{x}_{-m-1t} \right) \mu_{m+1t} \\ &- \left(x_{mt} + x_{-mt} + \tilde{x}_{-mt} + \delta \right) \mu_{mt} + o\left(\Delta t \right) / \Delta t. \end{aligned} \tag{F.27}$$

As is clear, these laws of motion remain unchanged despite population growth.

Corollary 1 *While a decline in population growth η mechanically decreases the growth rate of the aggregate output, the scaled economy and aggregate variables in per-capita terms work just as in the model without population growth. Notably, firm dynamics that are key to the main mechanism analyzed in the paper are not particularly affected by the population growth. Finally, while η enters the value functions of firms also through the discount rate $\hat{\rho}$, our robustness exercise on the interest rate analyzing a decline in the discount rate affirms that the effect of this channel on firm dynamics is quite muted.*

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G Robustness Analysis

This section assesses the robustness of our main quantitative results under five alternative specifications. In each exercise, we recompute the transitional dynamics and the contributions of each channel as in Section 6.3. Table G.2 summarizes these decomposition results, and for brevity, we present only the effect of the knowledge diffusion channel, with the first column of the table showing the baseline results for reference.

Table G.2: Robustness Analysis for Decomposition Results: Knowledge Diffusion Channel

	Baseline	**Zero tax**	**Low ϕ**	**High ϕ**	**High ψ**	**Quadratic R&D cost**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Entry	24.5%	17.4%	13.0%	28.7%	9.0%	32.7%
Labor	109.8%	137.4%	108.9%	133.4%	108.8%	108.9%
Markup	91.4%	83.9%	88.5%	92.8%	87.7%	89.1%
Profit	109.8%	137.4%	108.9%	133.4%	108.8%	108.9%
Concentration	87.4%	77.4%	83.8%	89.9%	82.2%	84.3%
Young firms	60.7%	48.2%	46.0%	60.7%	47.4%	63.3%
Prod. gap	90.1%	81.8%	87.1%	91.8%	86.1%	87.0%
Reallocation	66.3%	49.4%	52.1%	65.5%	53.6%	76.4%
Dispersion	60.7%	39.4%	45.1%	57.9%	45.2%	45.3%

Notes: Percentage values measure the share of the contribution from the knowledge diffusion channel to the total model-generated deviation between 1980 and 2015. Negative values mean that adding the knowledge diffusion channel moves the model-generated variable in the opposite direction of the empirical counterpart. A value larger than 100 percent means that the difference between the hypothetical and empirical paths is larger than the observed variation.

G.1 Revisiting Effective Corporate Tax Rates

As discussed in Online Appendix A, corporations take advantage of several regulatory loopholes to decrease their effective tax burden. Therefore, to the extent these practices became more common in recent decades, there might be a concern as to whether the decline in average effective corporate tax rates has been more dramatic than what we have penciled into our calibration based on national accounts data. In that case, we would artificially restrict the potential role the changes in corporate tax rates could actually play in driving model-based responses. To alleviate this concern, we consider an extreme case where we assume that corporate tax rates decline to 0 percent over the transition period. Setting $\tau_T = 0$ and keeping the rest of the parameters determined by the initial BGP fixed, we reran our transition calibration. Column 2 in Table G.2 shows the decomposition results based on the new transition path. The quantitative magnitudes are quite similar to the baseline decomposition, corroborating our original findings that exhibit the significant contribution of a decline in knowledge diffusion to the model-based dynamics.

G.2 Alternative Values for Drastic Innovation

In the model, drastic innovation and knowledge diffusion both lead to a quick catch-up of follower firms. By decoupling the two channels, we allow firms the chance to endogenously gen-

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erate drastic innovations even when there are distortions to the knowledge diffusion channel. In this way, we avoid assigning an artificially large importance to knowledge diffusion and grant a fair treatment to other potential channels of interest. However, having two similar sources of quick catch-up may raise questions about their identification. Reassuringly, the sensitivity analysis in Section 4.3 demonstrates that exogenous knowledge diffusion has a much stronger effect on margins such as markups and profits than the endogenous drastic innovation channel does. Yet we still find the robustness of our quantitative results to alternative values of ϕ worth discussing. To this end, we recalibrate the transition of the model under the assumption of a low and a high value of ϕ and regenerate our decomposition results in these alternative environments.

We start with a discussion of the low-ϕ case. Setting ϕ to one-fifth of the original value while keeping other parameters listed in Table 1 fixed, we recalibrate the parameters that define the transition path of the model. Next, we recompute the quantitative effect of the recalibrated decline in knowledge diffusion intensity. The results, shown in the third column of Table G.2, demonstrate that the original findings still go through: The knowledge diffusion channel has a pretty strong role in explaining the transition path of the model variables. Next, we repeat the same exercise with a high value of ϕ, which we set to about 5 percent, five times the baseline value. This considerable increase spoils the initial BGP match of the model, and we therefore recalibrate it as well in this exercise. A higher value of ϕ decreases the initial level of δ and diminishes the scope for the knowledge diffusion channel in the model. Still, the fourth column of Table G.2 shows that the explanatory power of the decline in knowledge diffusion remains intact—i.e., it is the main driver of declining business dynamism.

G.3 Curvature of Innovation Step Sizes

We explore the effects of the changes of several parameters in relation to the examination of alternative mechanisms in Section 8.1. However, the parameter ψ was not one of them. Therefore, here we discuss how our decomposition results change when we consider a higher level of ψ—specifically, $\psi = 0.96$ instead of the calibrated value 0.86. Since this change alters the initial BGP match considerably, we recalibrate the BGP in this exercise as well. The fifth column of Table G.2 presents the results based on the recalibrated transition path in this specification. While the effect of the knowledge diffusion channel on the entry rate is diminished in this specification, the main message goes through unaltered again.

G.4 R&D Elasticity

In quantitative Schumpeterian growth literature, a commonly used value for the labor elasticity of R&D expenditure is 0.5, implying a quadratic R&D cost function (see Acemoglu et al., 2018 for a discussion). Therefore, we next repeat our decomposition exercise under the assumption of quadratic R&D cost functions. To this end, we recalibrate the model path, setting $\gamma = \tilde{\gamma} = 2$. The last column in Table G.2 presents the results based on the recalibrated transition path. Again, the findings are very much in line with the baseline results, suggesting that the choice of this parameter did not have a meaningful effect on the main takeaways.

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