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"TIME-RELEASE" OUTPUT RESPONSES TO PUBLIC EDUCATION EXPENDITURES

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This paper argues that output can respond to public education spending in a delayed and persistent manner through human capital accumulation. We refer to this as a "time-release" response, reflecting that the output response grows as students exposed to increased expenditures sequentially enter the labor market. We first develop and calibrate a stochastic overlapping generations model to formalize the propagation of spending shocks over a long time horizon. We then empirically explore this time-release aspect of shocks to government education expenditures on output using US state-level data for the period 1963–2016 and a panel structural vector autoregression methodology. Consistent with the model, our empirical results show that the dynamic response of output to shocks to government education expenditures is positive, significant, and long-lasting.

Keywords: Education Spending, Overlapping Generations Model, Vector Autoregressions

1. INTRODUCTION

Following the 2007 financial crisis and the subsequent recession, public investment in education decreased considerably in many US states. As early as spring 2008, many states had begun to implement budget cuts as the financial crisis and the recession had already significantly decreased revenues. The Center on Budget and Policy Priorities reports that by the end of fiscal year 2009, 34 states had cut spending on K-12 education and 43 had cut college and university expenditures.[1] In aggregate, this downward trend in spending began to reverse in 2013. While education expenditures are now generally rising, data for 2016 show that real per capita education expenditures in 24 states were still lower than pre-recession

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levels. Overall, then, the last decade saw substantial volatility in state and local government education expenditures.

The economic impact of such changes in spending has been a major public policy issue. As a consequence, an extensive body of theoretical and empirical literature has examined the output effects of changes in public education expenditures. While economic theory often predicts a positive impact of education expenditures on the level or growth of output, the empirical literature has yet to reach consensus on their relationship.[2] This literature typically focuses on the long-run effects of public expenditures by estimating cross-sectional or panel data regression models using data averaged over 5-year or 10-year periods and, therefore, ignores short-run dynamics.[3] A related literature focuses specifically on the dynamics of policy shocks more generally, but does not consider education spending, in particular. The structural vector autoregression (SVAR) literature uses impulse response analyses to trace out the dynamic response of output to a one time shock to government expenditures.[4] These studies generally compute impulse response functions for forecast horizons of 5 or fewer years, thereby concentrating on short-run responses.[5]

While it is plausible that certain government expenditures only have short-run impacts, this is unlikely to be the case for education expenditures. An important and distinguishing feature of public education spending is that its economic impact through human capital accumulation can occur with a considerable delay. Chetty et al. (2011), for example, provide evidence that small class sizes, and more experienced teachers in kindergarten, as well as higher quality classrooms in kindergarten through third grade are significantly correlated with adult earnings and other improved adult outcomes. Expenditures which improve class size or teacher quality for K-3 students, then, can have a positive effect on output. However, this effect will be seen only after 10 or more years when today's early primary students enter the labor market. The same is true of students at each stage of education. Complimentary evidence by Jackson et al. (2016) using the natural experiment of education finance reform in the 1970s and 1980s indicates that adult wages increased by 7% in response to a 10% increase in per pupil spending for each of 12 years of public education.

Results such as these highlight that the effect of any shock to public education spending is embodied in students' human capital. As such, the human capital effect of the shock is not fully felt in the economy until all affected students finish education and enter the labor market. Consider a one-time shock to education expenditures at each grade level in a setting where each year of schooling adds equally to a student's human capital. At the time of the shock, students are spread across 13 stages ranging from kindergarten to high school senior. Abstracting for now from college attendance, high school seniors will enter the labor market in 1 year with their human capital adjusted in relation to the spending shock. Since they comprise a small share of the labor force, the effect of this on output is small. As another year passes, high school juniors at the time of the shock enter the labor market. At this point, students affected by the shock comprise a larger share of the labor force and the effect of the shock grows. The full effect of the shock is not felt until those in kindergarten at the time of the shock go through all of schooling and enter the labor market. We refer to this gradual influence on output from a spending shock as a "time-release" effect.

Certainly this simple story requires many refinements. Education at each stage may not add equally to human capital so a student's education stage at the time of the shock matters. Shocks to school funding tend to be persistent so younger students are affected over a larger share of their education than are older students. The importance of human capital from education diminishes as workers gain experience and on-the-job-training. The timing of the effect depends on the extent to which students spend time in college after graduation, and so on. However, the key intuition is robust to such refinements: the time-release nature of the response of output to education spending allows for long-term propagation of a short-term shock.

This story does not argue against a significant short-term response to spending. Rather it argues that any such response works through a different channel. As a component of gross state product, a shock to education expenditures influences output directly and may precipitate further general equilibrium output adjustments. These effects can occur more rapidly, but are also more likely to be short-lived. Together, these channels allow an initial response to a spending shock that is immediate and relatively brief, followed by a delayed but relatively persistent response through human capital accumulation.

This time-release nature of human capital accumulation has not been central in previous policy analyses. To formalize the propagation of spending shocks over a long time horizon, we build and calibrate a stochastic overlapping generations model where the productivity of a generation depends on a composite of government education spending through childhood. Human capital in early adulthood is linked closely to childhood education, with this link gradually loosening throughout adulthood. We then consider how the economy responds to shocks to education spending, non-education spending, and output in the context of the model. While our key concern is on the response of output, we also consider the dynamics of key macroeconomic aggregates as well as several life cycle features of the economy. All shocks have qualitatively similar contemporaneous impacts and short-run dynamics. Education spending, however, uniquely has a secondary effect through human capital and is propagated in a time-release fashion.

We next conduct an empirical investigation of the potential time-release aspect of shocks to government education spending. In particular, we explore the short-run and long-run dynamics stemming from an education spending shock using the SVAR approach. Unlike much of the SVAR literature, we use a *panel SVAR* methodology, which allows us to make use of US state-level data. This methodology has several advantages. First, our data are annual for the period 1963–2016 for the 50 states and the District of Columbia (DC), resulting in 52 observations per state. This relatively short time dimension makes traditional VAR estimation unsuitable for identifying the effects of shocks to education expenditures for each state. Pooling the data, however, results in a large enough sample to effectively identify the effects of public education spending on output. Second, the VAR literature on the macroeconomic impact of government spending shocks is extensive, implying that the identification restrictions are well documented. Finally, the use of a VAR methodology helps us to quantify the average importance of these shocks by means of variance decompositions. To the best of our knowledge, our analysis represents the first attempt to apply this methodology to education spending in particular. As such, it is the first attempt to explore the potential long-term propagation of shocks to education spending.

The use of US state-level data as a distinguishing aspect of our empirical investigation is worth emphasizing. Much of the literature on the effects of government education expenditures has relied on cross-country data. Economic analyses using cross-country data have often been criticized on grounds of data quality, measurement error, and international comparability (Deininger and Squire (1996)). Differences in data definitions and collection methods across countries raise comparability and quality issues, which can impact empirical estimates in unpredictable ways. This problem is especially concerning for cross-country data on public education expenditures. Many of the cross-national studies use public education expenditures from different levels of government (general, central, or local). In many developing countries, almost all investments in public education come from the central government, whereas in the USA and many other advanced countries, the majority of public spending on education comes from state and local governments (Devarajan et al. (1996)). It should come as no surprise then that the empirical literature is saturated with contrasting findings on the output effects of public education expenditures. By using US state-level data, we mitigate these measurement error, data quality, and international data comparability problems.

Several caveats about the empirical model must be acknowledged. First, shocks to government education expenditures are identified using the SVAR approach of Blanchard and Perotti (2002). While the literature is thick with papers that employ this identification strategy, it has recently been challenged for its supposed inability to time expectations and foresight (Ramey and Shapiro (1998)). Leeper et al. (2013) point out that shocks to government expenditures identified by VAR timing restrictions may be anticipated if there is significant delay between the announcement and implementation of the policy change. These papers propose a narrative approach, which uses news sources to identify dates when agents learn about impending public spending increases. Ravn et al. (2012), however, argue that the narrative and the SVAR approaches capture different types of government spending shocks, pointing out that the narrative approach captures anticipated shocks, while the SVAR methodology identifies unanticipated shocks. Ilzetzki et al. (2013), who use a panel VAR model with timing restrictions similar to that in this paper, provide some evidence that shocks to government consumption recovered from a VAR model are largely unanticipated.

The second caveat is related to our use of annual data. Blanchard and Perotti (2002) argue that the validity of their identification strategy relies on the use of high-frequency data. They argue that “decision and implementation lags in fiscal policy imply that, at high enough frequency—say, within a quarter– there is little or no discretionary response of fiscal policy to unexpected contemporaneous movements in activity” (p. 1330), further arguing that the key to their identification procedure is that using quarterly data “virtually eliminates” this concern. Beetsma et al. (2006, 2008, 2009) and Beetsma and Giuliodori (2011), however, show that this assumption may not be too restrictive for annual data.

Our key empirical results are broadly consistent with the impulse responses of output generated by our theoretical model. First, a shock to state and local public education expenditures increases output through both a short-run effect and a time-release effect. We find that the response of output to a shock to education spending displays double hump-shaped and persistent dynamics, with peak effects occurring 3 and 13 years after the shock. We argue that the first peak corresponds to the positive short-run impact resulting from the fiscal stimulus, while the second peak reflects the time-release impact arising from human capital accumulation. Second, the output effects of non-education expenditures are short-lived, consistent with the view that other expenditures have no long-run effects on the economy beyond the effects of the stimulus. Third, shocks to education expenditures explain only a small fraction of the variability in output in the short run, but a sizable proportion in the long run. Since the key innovation in our model is the explicit representation of the natural time structure of human capital production, we conclude that our empirical findings are supportive of the long tradition of modeling government spending as an input in the production of human capital. Our results further suggest that human capital is the channel through which the observed long-term propagation of education shocks arises.

The rest of the paper is organized as follows. Section 2 presents and calibrates the theoretical model. Section 3 outlines our empirical strategy and discusses the empirical results. Concluding remarks are contained in Section 4.

2. MODEL

In this section, we build a life cycle model which allows the propagation of spending shocks over a long time horizon through the effect of government education spending on human capital accumulation. In this stochastic general equilibrium model, a period represents a single year. A representative agent is born in each period. The agent born in period $t - n_c$ enters adulthood in period t, so that n_c is the number of periods spent in childhood. The agent spends the final n_e periods of childhood in formal education, n_w periods as a worker, and n_r periods in retirement. In period $n_p < n_w$ of her working life, the agent has one child so $n_p + n_c$ is the length of one generation. Since the long duration of the response to a spending shock in our model is due to the time structure of human capital accumulation, we begin with a description of this process.

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2.1. Human Capital

Agents spend the final n_e periods of childhood acquiring human capital and are indexed by the period that they enter the labor force. At this point, their endowment of human capital is given by:

$$h_{t,t} = Be_t^{\mu} \tag{1}$$

so that $h_{t,t}$ is the human capital of the generation t agent (first subscript) in period t (second subscript). This depends on an education composite e_t for the period t agent. $B > 0$ scales productivity and $0 < \mu < 1$ governs the elasticity of e_t in generating human capital.

The education composite reflects that human capital accumulation spans the n_e years spent in school and depends on government education spending at each stage. Specifically, we set:

$$e_t = \left(\sum_{j=1}^{n_e} \eta_j G^{\varphi}_{j,(t-1)+j-n_e} \right)^{\frac{1}{\varphi}}.$$

The subscript j refers to a particular period of school, and $G_{j,t}$ is period t government expenditure on this stage of education. Lagged rather than current spending at each stage influences the human capital of a period t adult. For example, suppose education lasts 13 periods. Then, a period t agent was in the 13th stage of childhood in period $t-1$. Government spending on the 13th stage of education in period $t-1$ is an argument in this agent's human capital. With $j = 13 = n_e$, this is denoted by $G_{13,t-1}$. Government education spending on the 12th stage of education in period $t-2$ is another argument in this agent's human capital. With $j = 12 = n_e - 1$, this is denoted by $G_{12,t-2}$. This pattern continues through $G_{1,t-13}$. The elasticity of substitution across these inputs is $\frac{1}{1-\varphi}$, and share parameters, summing to one, are given by $\eta_j \geq 0$.

Lifetime human capital evolves according to:

$$h_{t,t+a} = h_{t,t}(1-\delta_e)^a + x_{t,t+a}. \tag{2}$$

Here, $a \in \{0, 1..., n_w + n_r - 1\}$ indicates the number of periods of adulthood completed, so that $h_{t,t+a}$ is the human capital of the period t agent upon completing a years of adulthood. Initial human capital from education depreciates at rate $0 \leq \delta_e \leq 1$. However, accumulated work experience adds to human capital. This is reflected by the term $x_{t,t+a}$ where $x_{t,t} = 0$ and $x_{t,t+a}$ is increasing in a. This specification allows us to match several life cycle patterns of earnings. We provide details on equation (2) in the discussion of the calibration.

Including government education expenditures in a human capital production function is common in the endogenous growth literature which considers government education policy.[6] This literature generally includes factors such as private education spending, ability, time allocations, or parental human capital in addition to government education spending. While we do not consider endogenous

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growth, such features can be incorporated into our framework as well. However, our purpose is to demonstrate that shocks to government education spending can be propagated slowly through human capital accumulation. We abstract from features which are not required to make this point. This keeps the presentation of the model relatively simple despite the stochastic environment with many periods. Including parental human capital in the human capital production function serves mostly to scale our findings. We expect our results to be robust also to other features which preserve the notion that government spending has delayed effects on human capital available in the labor force. For example, family education spending may respond to government education spending. If family spending was included in the model, this general equilibrium response would alter the overall magnitude of responses to shocks. However, the time-release nature of this response will not be fundamentally altered.

For similar reasons, we do not model college education distinctly. Jackson et al. (2016), among others, show that increased K-12 spending by states results in increased college enrollment. This provides an additional mechanism through which spending can increase human capital. While this will alter to some extent the timing of the impact of spending on human capital available in the workforce, the effect works in the same direction as the mechanism we model. As such it will magnify rather than overturn the key point of a delayed response. For the sake of simplicity, we abstract from this additional effect.

2.2. Agent's Problem

Each cohort derives utility from consumption, $c_{t,t+a}$, in each period of adulthood and derives disutility from labor, $\ell_{t,t+a}$, in each period as a worker. Expected lifetime utility of a period t agent, U_t, is given by:

$$U_t = E_t\left(\sum_{a=0}^{n_w+n_r-1} \frac{\beta_a c_{t,t+a}^{1-\theta}}{1-\theta} - \sum_{a=0}^{n_w-1} \frac{\beta_a \gamma_a \ell_{t,t+a}^{1+\nu}}{1+\nu}\right), \tag{3}$$

where E_t is the expectations operator in period t and $\theta, \nu \geq 0$. Here, $\frac{1}{\theta}$ is the intertemporal elasticity of substitution for consumption and $\frac{1}{\nu}$ is the Frisch elasticity of labor supply. Discounting across the life cycle is governed by the sequence β_a, and the disutility associated with work is governed by the sequence γ_a. These specifications are more general than the common case where γ_a is fixed and $\beta_a \equiv \beta^a$. We choose specifications which allow us to match several life cycle features of consumption and labor hours. Each of these is discussed in the Calibration section.

The agent chooses consumption, labor, and savings in each period to maximize equation (3) taking equation (1) as given, and subject to the period budget constraints given by:

$$w_{t+a}h_{t,t+a}\ell_{t,t+a}\left(1-\tau_{\ell,t+a}\right) + s_{t,t+a-1}\left(1+r_{t+a}\left(1-\tau_{s,t+a}\right)\right) = c_{t,t+a} + s_{t,t+a} + \tau_{t+a}. \tag{4}$$

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The first item on the left is net labor income after completing a periods of adulthood. The wage per unit of human capital in that period is given by w_{t+a}. This is multiplied by human capital supplied per unit of time worked, by $\ell_{t,t+a}$, and by $\left(1-\tau_{\ell,t+a}\right)$ where $\tau_{\ell,t+a}$ is the tax rate on labor income. During periods of retirement, $\ell_{t,t+a}=0$. Previous period saving or borrowing is $s_{t,t+a-1}$. The per unit return to savings, r_{t+a}, is taxed at rate $\tau_{s,t+a}$, and negative returns are deductible for borrowers. Thus, the second item on the left for $a>0$ is net income from savings if positive and the net cost of debt repayment if negative. For $a=0$, this is 0 since the agent begins life with no savings or debt. The right-hand side of equation (4) comprises consumption, saving, and a lump sum tax, τ_{t+a}. All workers pay the same tax rates and lump sum tax in any period, but any worker may pay different rates and levels in different periods of their adulthood. As such, the $t+a$ notation for taxes indexes time rather than agents.

Optimization yields the following Euler equation for each period of adulthood $a<n_w+n_r-1$:

$$1=\frac{\beta_{a+1}}{\beta_a}E_{t+a}\left(\frac{c_{t,t+a}}{c_{t,t+a+1}}\right)^{\theta}\left(1+r_{t+a}\left(1-\tau_{s,t+a}\right)\right). \tag{5}$$

In period $a=n_w+n_r-1$, agents simply consume the proceeds of savings and pay taxes. The optimal intratemporal trade-off between consumption and leisure is given by:

$$\gamma_a c_{t,t+a}^{\theta}\ell_{t,t+a}^{\nu}=w_{t+a}h_{t,t+a}\left(1-\tau_{\ell,t+a}\right) \tag{6}$$

when $a\leq n_w-1$ and labor is equal to zero otherwise. Equations (5) and (6) demonstrate that taxation to fund education is distortionary when either income is taxed. This motivates us to include the lump sum tax as well. By assuming lump sum taxation, we are able to focus our discussion on the effects of expenditures absent these distortions. We subsequently discuss how the distortionary effects of required taxation alter the discussion.

2.3. Firm's Problem and Capital Accumulation

A representative firm produces a single final good in period t, Y_t, according to:

$$Y_t=\phi_{y,t}K_t^{\alpha}L_t^{1-\alpha}$$

with share parameter $0<\alpha<1$ and the total factor productivity scalar $\phi_{y,t}>0$. K_t is the period t capital stock. The labor input, L_t, is the sum of all units of human capital employed by the firm in period t. The stochastic element of output is total factor productivity, $\phi_{y,t}$ which follows an AR(1) process:

$$ln\phi_{y,t}=\rho_y ln\phi_{y,t-1}+\varepsilon_{y,t},$$

where the white noise shock $\varepsilon_{y,t}$ is such that $E\left(\varepsilon_{y,t}\right)=0$ and $E\left(\varepsilon_{y,t}^2\right)=\sigma_y^2$. All markets are competitive so that factor prices are equal to marginal products, giving:

$$w_t = \frac{(1-\alpha)\, Y_t}{L_t} \tag{7}$$

$$r_{k,t} = \frac{\alpha Y_t}{K_t}, \tag{8}$$

where w_t is the wage per unit of labor input and $r_{k,t}$ is the rental rate of capital. The capital stock accumulates according to:

$$K_{t+1} = (1-\delta_k)\, K_t + I_t, \tag{9}$$

where I_t is the investment in new capital, δ_k is the depreciation rate on physical capital, and K_{t+1} is the capital stock available in period $t+1$.

2.4. Government

The government imposes a lump sum tax on all individuals and a proportional tax on all income. It uses revenue to fund education and to pay for a non-education government input. The period t budget constraint is:

$$(n_w + n_r)\, \tau_t + \sum_{a=0}^{n_w-1} w_t h_{t-a,t} \ell_{t-a,t} \tau_{\ell,t} + \sum_{a=0}^{n_w+n_r-1} s_{t-a,t-1} r_t \tau_{s,t} = G_{e,t} + G_{u,t}. \tag{10}$$

The left-hand side of equation (10) totals tax revenue currently paid by all active generations from the lump sum tax and the proportional taxes on both sources of income, with negative returns deductible for borrowers. Revenue is used to pay for education, $G_{e,t}$, and a non-education expenditure, $G_{u,t}$. Government education spending encompasses current spending on all students at the various stages of childhood. As mentioned above, $G_{j,t}$ is the current spending on children in period j of education, so that $G_{e,t} = \sum_{j=1}^{n_e} G_{j,t}$.

Government spending is a source of uncertainty in this model. We assume $G_{e,t}$ and $G_{u,t}$ are governed by:

$$\begin{aligned} G_{e,t} &= \phi_{e,t} g_e Y_t \\ G_{u,t} &= \phi_{u,t} g_u Y_t, \end{aligned} \tag{11}$$

where g_e and g_u are the steady-state shares of output spent by government on education and the non-education item. The stochastic scalars $\phi_{e,t}$ and $\phi_{u,t}$ are determined by the AR(1) processes:

$$ln\phi_{e,t} = \rho_e ln\phi_{e,t-1} + \varepsilon_{e,t}$$
$$ln\phi_{u,t} = \rho_u ln\phi_{u,t-1} + \varepsilon_{u,t}$$

with $0 \leq \rho_e, \rho_u < 1$. The white noise shocks $\varepsilon_{e,t}$ and $\varepsilon_{u,t}$ have properties $E(\varepsilon_{e,t}) = E(\varepsilon_{u,t}) = 0$, $E(\varepsilon_{e,t}^2) = \sigma_e^2$ and $E(\varepsilon_{u,t}^2) = \sigma_u^2$.

2.5. Equilibrium

In equilibrium, all agents take factor prices and tax rates as given and, in general, choose consumption, savings, and leisure as determined by equations (5) and (6). However, retired workers instead set labor to 0 and in their final period of retirement consume income net of taxes. Firms hire capital and labor to maximize profits taking factor prices as given, which generates equations (7) and (8). Furthermore, the government sets its budget as in equation (10), and the return to savings is $r_t = r_{k,t} - \delta_k$. The stock of physical capital accumulates according to (9), and human capital for each generation moves according to equation (2).

Equilibrium also requires that markets clear. For the goods market, this is:

$$Y_t = \sum_{a=0}^{n_w+n_r-1} c_{t-a,t} + I_t + G_{e,t} + G_{u,t}. \qquad \textbf{(12)}$$

Equation (12) indicates that all output is consumed by the variously aged current adult consumers, invested, or used by government. Labor market clearing requires:

$$L_t = \sum_{a=0}^{n_w-1} \ell_{t-a,t} h_{t-a,t} \qquad \textbf{(13)}$$

and capital market clearing requires that the entire capital stock is employed by the representative firm. Finally, in equilibrium, net savings from currently active agents are used to purchase capital to bring to the next period which gives:

$$\sum_{a=0}^{n_w+n_r-1} s_{t-a,t} = K_{t+1}. \qquad \textbf{(14)}$$

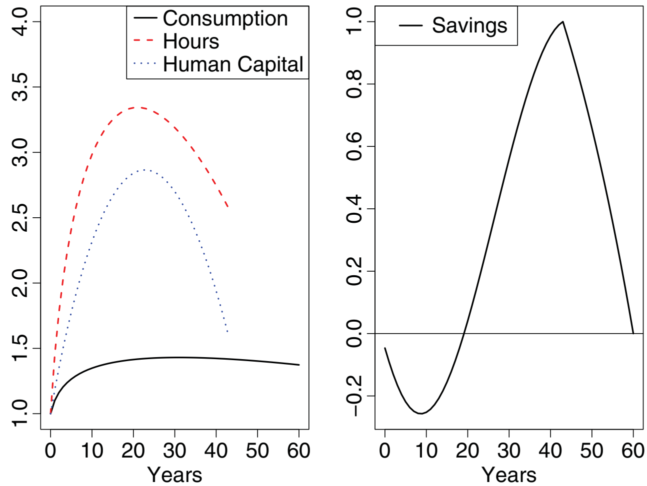
2.6. Calibration

In this subsection, we provide an outline of how to find the steady state and calibrate the model. A detailed unpublished appendix describing the exercise, along with the relevant code, is available from the authors. We set $n_e = 13$ to match the mean years of schooling for workers over the age of 25 in the USA.[7] With schooling usually starting at age 5, this gives $n_c = 18$. The Bureau of Labor Statistics reports an average retirement age of 62 so $n_w = 44$.[8] According to the Centers for Disease Control and Prevention (CDC), life expectancy in the US is nearly 79 years so n_r=17.[9] The CDC also estimates that the average age of first time mothers is 25, so we use this to set $n_p = 7$.[10] For our baseline model, we use $\theta = 1$, which is common in the literature, and $\nu = \frac{1}{3}$ so that the Frisch elasticity of labor supply is in the middle of the range commonly used by macroeconomists (Peterman (2016)). We set $r = 0.038$, which is the average value from 1961 to 2018 reported by the World Bank, and α=1/3, as is common in the literature.[11] Equilibrium conditions require $\delta_k = 0.065$.

Our calibration of β_a, γ_a, and $x_{t,t+a}$ is motivated by several observed characteristics of the life cycle. First, consider β_a. The steady-state counterpart to equation (5) gives $\frac{c_{a+1}}{c_a} = \frac{\beta_{a+1}}{\beta_a} r$. In the typical case where $\frac{\beta_{a+1}}{\beta_a} = \frac{\beta^{a+1}}{\beta^a} = \beta$, consumption is restricted to grow at constant rate through adulthood. However, consumption over the life cycle is single-peaked. We allow for non-monotonicity in consumption by calibrating non-monotonicity in the discount parameter. Specifically, we normalize $\beta_0 = 1$ and assume $\beta_a r^a = (a+1)^{\Phi_1} - \Phi_2 a$. Fernández-Villaverde and Krueger (2011) show that consumption peaks at age 50, and at that point is 30% higher than at age 20. To match this, we solve numerically for values of Φ_1 and Φ_2 such that in a steady-state equilibrium, consumption is maximized at c_{31}, where $c_{31} = 1.3c_1$. Note that since $a = 0$ at age 19, $a = 1$ at age 20, and $a = 31$ at age 50. This requires $\Phi_1 = .148$ and $\Phi_2 = 0.00771$.

We set labor hours on average to be one-third and choose parameters to match this. This is a common choice in the literature. It is also close to 31.5% of time spent working found by Gomme and Rupert (2007) for individuals aged 16–64. Since we leave out individuals under 18, who work fewer hours, one-third is roughly consistent with this. Like consumption, hours worked are single-peaked across the life cycle. Because of this, our estimation strategy for γ_a is similar to our strategy for β_a. Specifically, we hold average hours equal to one-third but allow hours worked in any period to vary according to $l_a = (a+1)^{\Phi_3} - \Phi_4 (a+1)$. The Bureau of Labor Statistics reports that hours worked peak between ages 35 and 44, and at this point are 65% higher than average hours worked for those aged 20–24.[12] We take the midpoint of these time intervals and calibrate hours worked to match these features of life cycle labor hours. We solve numerically for values of Φ_3 and Φ_4 such that in a steady-state equilibrium, hours worked is maximized at l_{21} (age 40) and at that point is equal to $1.65 l_3$ (age 22). This requires $\Phi_3 = 0.649$ and $\Phi_4 = 0.219$. We then normalize the series to average one-third. We choose the corresponding sequence of γ_a values from the steady-state analog to equation (6). For this calculation, the consumption values are derived from equation (5). The sequence of human capital values is discussed below.

We next turn to calibrating the sequence of $x_{t,t+a}$ values in equation (2). From this expression, we see that initial human capital depreciates through the life cycle. With no offsetting additions to human capital, this would cause wages per hour worked to fall through life. Lagakos et al. (2018) show that in fact lifetime wages increase early in a career and peak at between 20 and 30 years of work experience. At this point, they are about 90% higher than during the first 4 years of work. Since the wage per unit of time is fixed in a steady state, this requires that human capital accumulates through most of life and then falls. This in turn requires an increase in human capital sufficient to offset depreciation through most of the life. We assume that this increase comes simply from gaining more years of work experience. To capture this, we set $x_{t,t+a} = \left(\Phi_5 a^{\Phi_6} - \Phi_7 a\right) h_{t,t}$. This is similar to our earlier specifications but has an additional parameter, Φ_5. The additional parameter is required to assure that experience gains are large



Notes: The solid black curve in the first panel shows steady-state consumption for each year of adulthood. The dashed red curve and dotted blue curves show steady-state hours worked and human capital throughout the working life. Values are normalized by the levels in period one of adulthood. The second panel shows steady-state savings through adulthood normalized by the highest level of savings.

FIGURE 1. Life cycle patterns.

enough earlier in life so that the worker's wage increases while human capital from schooling depreciates. We solve for values of Φ_5, Φ_6, and Φ_7, such that in a steady-state equilibrium, human capital is maximized at age 43. At this point, it is 90% higher than at age 22. Additionally, human capital early in life increases sufficiently to overcome depreciation so that the human capital profile is a smooth, single-peaked function of age. This yields $\Phi_5 = -.0137$, $\Phi_6 = 1.73$, and $\Phi_7 = 17.9$.

The implications of our calibration strategy for β_a, γ_a, and x_a are shown in the first panel of Figure 1. The solid curve shows steady-state consumption over the 61 periods of adulthood, normalized by its initial value. Consumption rises rapidly when young, peaks at age 50 (period 31 of adulthood), and remains relatively high through retirement. The dashed and dotted curves show normalized hours and human capital over the 44 working periods of adulthood. These follow a similar pattern as consumption but peak at ages 40 and 43 (periods 21 and 24 of adulthood). Both vary more over the life cycle than consumption, and hours worked shows the largest overall change. The second panel shows life cycle savings, which facilitates these disparate consumption and earnings profiles, where savings are normalized by its highest level. We see that the agent borrows for the first 8 years of adulthood, then begins to pay off borrowing and build up savings for retirement. At retirement, she begins to spend down savings, and zeros this out in the final period. This savings pattern has an influence on the time structure of a response to a spending shock as discussed below.

While our calibration is useful for replicating life cycle characteristics of consumption, hours worked, and income, we note that a more standard formulation with a constant discount rate and disutility parameter does not substantially change the impulse response functions presented below. Those results feature aggregates and are not highly sensitive to the life cycle features of consumption and labor hours. Our specification of human capital is more consequential. A common alternative to equation (2) is to simply set $h_{t,t+a} = h_{t,t}\,(1+z)^{\,a}$, where z is the growth rate of human capital through experience. While this specification preserves our key results, it overstates the duration of responses to government expenditures. In this case, a shock to education spending will not diminish until affected students begin to retire. Of lesser importance, this specification disallows the observed hump-shaped life cycle earnings profile. To address each of these concerns, we adopt our more general specification where human capital is determined principally by schooling early in life, and principally by work experience later in life.

Government spending tends to be persistent. Regressing education spending on its lagged value shows that persistence parameters across the 50 states and DC range from 0.81 to 0.97 and average 0.93. We set $\rho_e = 0.93$. For consistency in comparing the impact of shocks in our model, we also set $\rho_y = \rho_u = 0.93$. We set g_e and g_u to match education and non-education spending as shares of output in the data described in Section 3. This gives $g_e = 0.0535$. In the empirical section, we consider several different types of government expenditures. For our calibration, we set $g_u = 0.0204$ corresponding to the share of output spent on public protection, which is one of the measures of government expenditures discussed below. For simplicity, we set $\tau_{\ell,t} = \tau_{s,t}$ and set this rate as required by the government budget constraint with no bond holdings. In the non-stochastic steady state, this is 0.093. From Education at a Glance (2018, p. 256), spending per student in lower secondary and upper secondary education is 8% and 15% larger than spending on primary education. We define g_1 through g_{13} to be the share of total education spending at each stage of education. With education shares summing to 1, this implies that spending on each of the 9 years of kindergarten through eighth grade is 7.43% of total spending so, g_1 through g_9 are set at 0.0743. The proportionally larger values of spending in lower and upper secondary education require $g_{10} = g_{11} = 0.0802$ and $g_{12} = g_{13} = 0.0854$.

Little guidance is provided in the literature for calibrating the remaining human capital parameters. However, our results are not sensitive to many of these, since the key feature is that education spending across a broad swath of childhood determines initial human capital. We set each $\eta_j = \frac{1}{13}$ and normalize B to 1. Following Blankenau and Youderian (2015), we set φ=−0.78. Results are most sensitive to our choices of μ and δ_e. We set $\mu = 0.85$ and δ_e= 0.05 as our benchmarks and show results for several other parameter choices.

For our baseline calibration, we set $\tau_\ell = \tau_s = 0$ so that all revenue comes from the lump sum tax. The magnitude of the lump sum tax is chosen to satisfy the government budget constraint. Considering lump sum taxation allows our discussion

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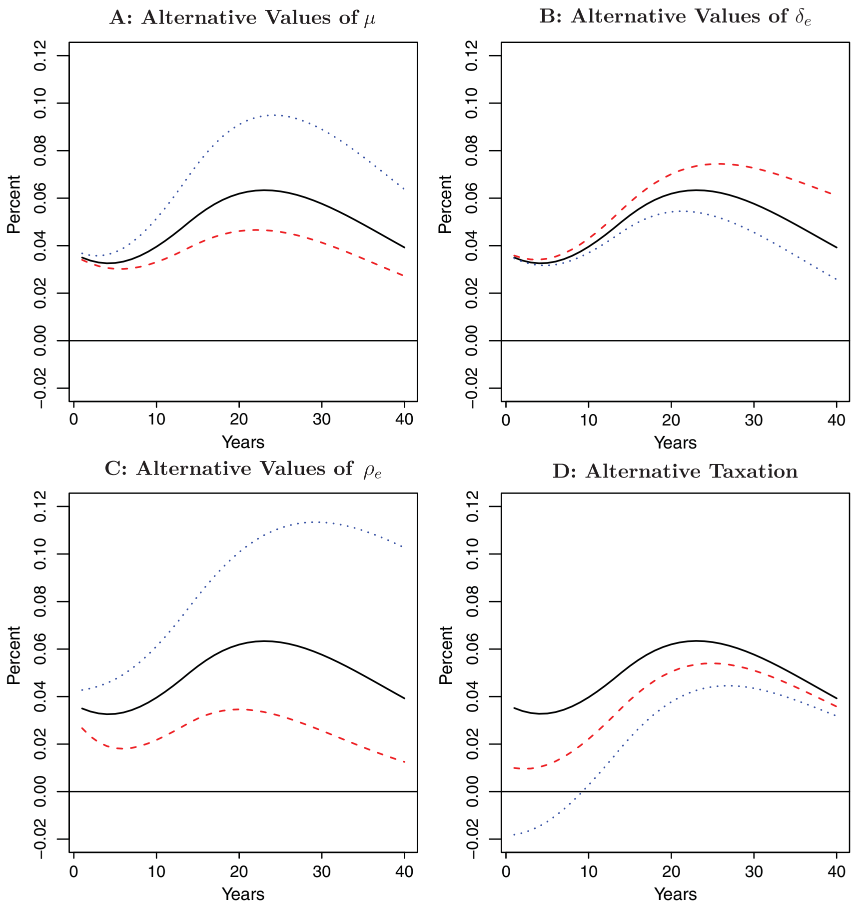
of the results to focus on the effects of expenditures without simultaneously accounting for the distortionary effects of taxation. However, these distortions can have important implications, and we consider this in a sensitivity analysis.

2.7. Solution

We use Dynare to find a first-order approximation to the solution of the model around the non-stochastic steady state.[13] In this subsection, we consider the response of the model to three types of shocks. We first present our main result by considering the output response to an education spending shock for the baseline parameterization and several alternative specifications. For comparison, we then consider the response to non-education spending and total factor productivity shocks. Next, we take a deeper look at the dynamic response to shocks by considering several other macroeconomic aggregates. We conclude with a discussion of how an education spending shock affects some of the life cycle features captured by the model.

2.7.1. Output response to education spending shocks. Figure 2 shows the main implications of the model. It maps out the output response of a 1% shock to education expenditures. In each panel, the middle curve shows results for the baseline parameterization. The other curves show results for alternative choices of μ, δ_e, ρ_e, and the tax structure. Consider first the baseline parameterization. Upon impact, the increased demand for the final good due to government spending causes a short-run increase in output. This stimulative effect is smaller in each subsequent period, and consequently, output begins to fall. However, there is a secondary effect on output rooted in the increased human capital of students. This effect is initially small and dominated by the stimulative effect. Through time, this effect grows as more affected students enter the labor market. The human capital effect dominates by the fifth year after the shock. At this point, output again increases and is on the path to a second peak response. Eventually, this effect also diminishes. For the baseline parameterization, the secondary effect peaks in period 24 and does not fully die out even 40 periods after the shock.

The other curves demonstrate that this general pattern holds for a range of parameter values. The first and second panels show that μ and δ_e have little impact on output in the initial years following the shock. The upper curve in Panel A corresponds to the larger value of μ and the lower curve to the smaller value. We see that as a determinant of the effectiveness of expenditures, larger values of μ increase the height of the secondary effect, with the largest difference occurring toward the midpoint of the response. The lower curve in Panel B corresponds to the larger value of δ_e, and the upper curve to the smaller value. Larger values of δ_e decrease the height of the secondary effect. Since this parameter gauges the rate at which education depreciates, it principally affects the duration of the response. Panel C shows that the persistence of the shock, ρ_e, influences the degree to which the stimulus effect increases output in the early periods, the maximum impact of



Notes: In Panel A, the red-dashed curve, solid black curve, and dotted blue curve correspond to $\mu = 0.6,\ 0.85$, and 1.3, respectively; in Panel B, the curves correspond to $\delta_e = 0.025,\ 0.05$, and 0.075; in Panel C, they represent $\rho_e = 0.85,\ 0.93$, and 0.975. Panel D considers different tax structures. The solid black curve is the baseline case of lump sum taxation. The red-dashed curve and dotted blue curve represent half and all of revenue instead being generated by proportional taxation on all income.

FIGURE 2. Model output responses to an education spending shock for different values of μ, δ_e, ρ_e, and alternative taxation.

the secondary effect, and the overall duration of the impact of the shock. With a sufficiently large value of ρ_e, the shock can have relatively large effects even 40 periods out.

Panel D considers various tax structures. In our baseline model, all revenue is generated by a lump sum tax. Lump sum taxation clarifies the discussion of dynamics below as it allows us to focus on the expenditure side of fiscal policy, which is where our modeling innovation lies. Moreover, it breaks an otherwise tight link between marginal tax rates and education spending. This tight relationship is likely overstated in our model with proportional taxes on income and

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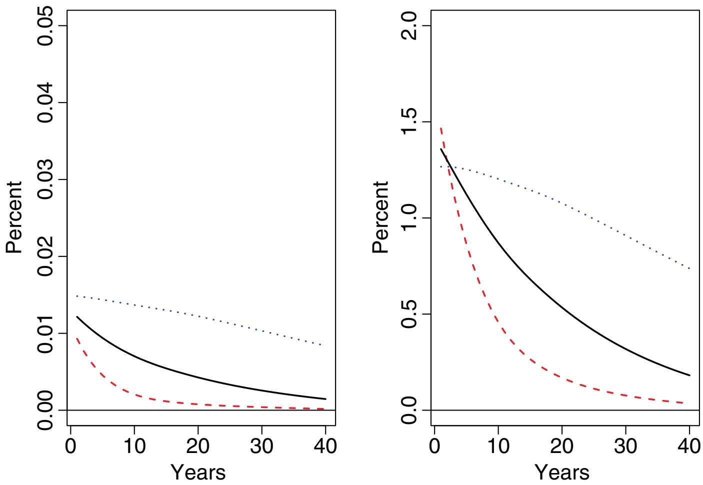
a period balanced government budget constraint. In general, states have various options beyond adjusting marginal tax rates to fund education spending. These include paying down savings, federal inputs, consumption taxes, property taxes, etc. which we do not model. Qualitatively, whether taxes are distortionary is consequential over the shorter run, but not over the longer run. The solid black curve is again our baseline case with lump sum taxation. The dashed red curve represents the case where half of all tax revenue is distortionary. We see that, in this case, the initial effect on output is smaller. This is because the distortionary tax on labor discourages work, putting downward pressure on the quantity of human capital employed and, through this, on output. When all taxes are distortionary, this effect dominates and increased education spending decreases output on impact, as represented by the dotted blue curve. Distortionary taxes on capital income also alter patterns of investment, and thus capital accumulation (not shown). Overall, however, distortionary taxes serve mostly to shift the impulse response downward at each time horizon without overturning the time-release nature of the response.

2.7.2. Output response to other shocks. We consider the effect of other shocks to emphasize that the secondary effect is distinct to education spending in our model. The impulse responses to shocks to non-education spending and total factor productivity are shown in Figure 3. The middle curve of the first panel shows the responses to a non-education expenditure shock under the baseline parameterization. The effect of the shock diminishes rapidly and exhibits no secondary effect. The upper curve, where $\rho_e = 0.975$, shows that the shock has a potential long-term effect only through persistence in shocks. The point is made more starkly with the lower curve, where the effect is nearly zero after 10 periods when we set the persistence parameter to 0.85 rather than 0.93. In the second panel, we see that the results are qualitatively similar for a total factor productivity shock.

2.7.3. Response of other aggregates to shocks. To better understand the dynamics of output, we explore and contrast the impulse responses of other macroeconomic aggregates following an education spending shock and a total productivity shock. These results are shown in Figure 4. The first panels of Figure 4A and B show the impact of each shock on the stock of employed human capital, given by:

$$H_t = \sum_{a=0}^{n_w - 1} h_{t-a,t}.$$

Aggregate human capital responds similarly to the two shocks. This is because education spending is in proportion to output so that a shock to productivity also increases education spending. With either shock, increased education spending has a slow, time-release effect on human capital. In the year of the spending increase, period t, there is no impact on human capital since only students are affected. The first affected cohort enters the labor market in period $t + 1$. However, these agents experience increased spending over a small part of their



Notes: The red dashed, solid black, and dotted blue curves correspond to $\rho_e = 0.85,\ 0.93$, and 0.975, respectively.

FIGURE 3. Model output responses to non-education spending and productivity shocks.

education. Also, any single cohort is a small part of the overall labor supply. As such, the impact on human capital is small one year out from the shock. The impact grows in the second year as period $t + 2$ agents enter the market. At this point, twice as many workers have been affected by the policy and period $t + 2$ agents have been affected twice as long. The relative impact of this additional year of exposure depends on the relative size of expenditures in period $t + 1$. This, in turn, depends on both period $t + 1$ output and its share spent on education as seen in equation (11). Though not shown here, the net effect is that education spending falls in each period subsequent to the shock. As such, the period $t + 1$ exposure has a diminished impact. Moreover, the impact of period t spending falls in period $t + 2$ due to depreciation. Still, the aggregate effect is an increase in human capital in period $t + 2$ relative to $t + 1$. In period $t + 3$, there are yet more affected workers and the new workers have exposure over a yet larger part of their childhood. These effects work to increase the impact of the shock. Falling education spending and human capital depreciation work counter to this. On net, the human capital stock grows further in period $t + 3$.

The length of exposure for entering cohorts grows each year until the youngest students in period t (period t kindergarten students) enter the market. Thereafter, all cohorts are exposed throughout schooling, and a growing share of the workforce has the maximum duration of exposure. This causes upward pressure on human capital. At the same time, education spending falls and the depreciation of human capital continues. Both of these put downward pressure on human capital. Spending drops off more rapidly with the productivity shock. This is because with a productivity shock, spending is above trend only because output is above trend

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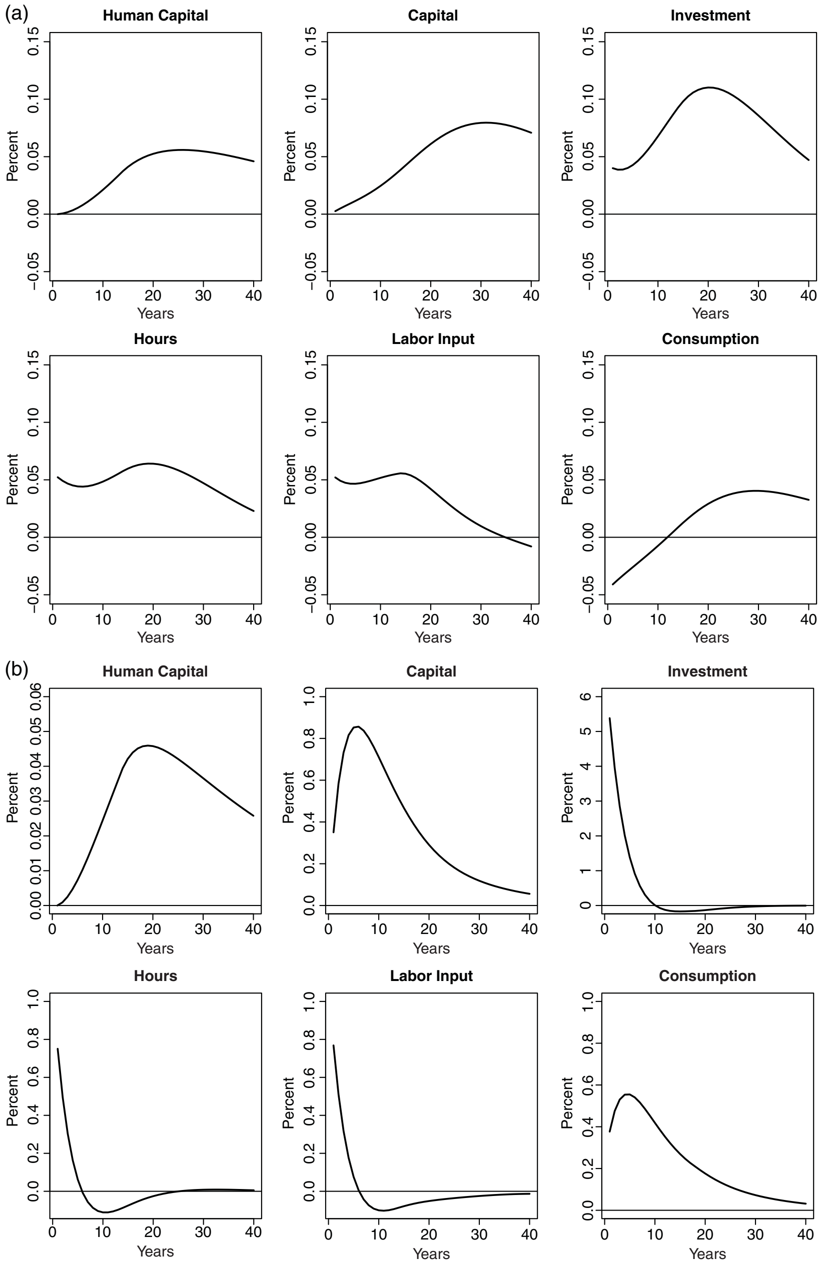

Notes: Panel A shows the impulse response of several aggregates to a shock to government education expenditures. Panel B shows how these same aggregates respond to a total factor productivity shock.

FIGURE 4. Model responses of other variables to education spending and productivity shocks.

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and this effect drops off relatively quickly. With the spending shock, the share of output spent on education is also above trend and this effect drops off more slowly. In either case, the downward pressures eventually dominate and human capital begins to taper off. This happens after 26 periods for the spending shock and after 19 periods for the productivity shock.

Despite generating similar effects on human capital, the second panels in Figure 4A and B show that the shocks generate quite different effects on physical capital. Investment increases sharply upon impact of a productivity shock, resulting in a large increase in the capital stock in the subsequent period. This impact on investment is shown in the third panel of Figure 4B. In contrast, the spending shock does not increase factor productivity directly. Instead, capital productivity increases only due to the increased supply of human capital and labor. Since human capital increases slowly, this contribution to capital productivity is delayed and the immediate effect on investment, and hence capital, is muted. This smaller impact on investment is shown in the third panel of Figure 4A. While a productivity shock motivates its largest investment increase on impact, an education spending shock has its largest effect 20 years after the shock.

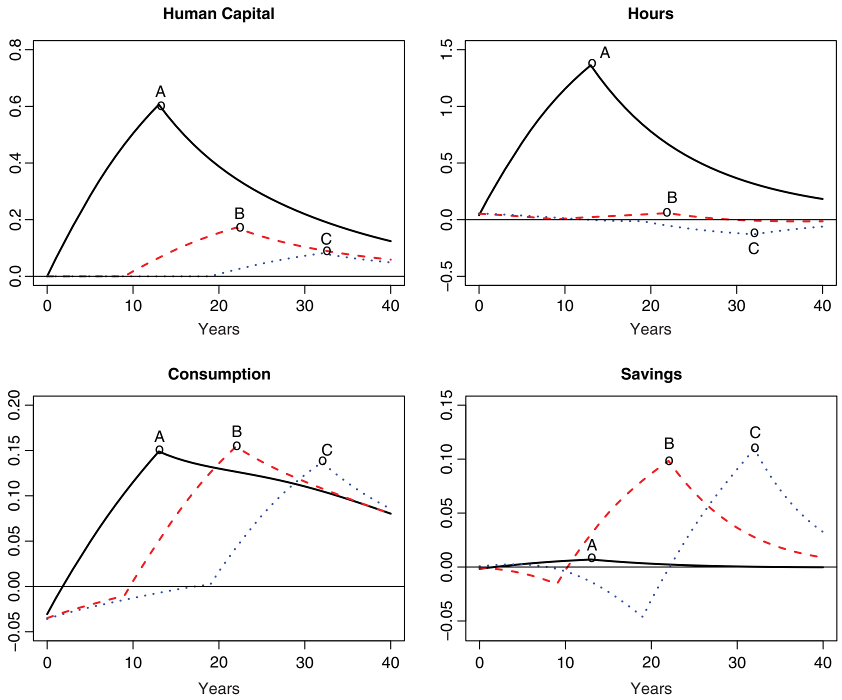
The fourth panels in Figure 4A and B show that each shock results in an immediate increase in the total number of labor hours supplied. For the spending shock, this increase is motivated mostly by the increased tax burden. Since this burden decreases consumption, decreased leisure (more working hours) is required for intratemporal optimization. This effect is present, too, with the productivity shock but in that case increased productivity is another motivating factor. As the productivity shock drops off, this factor diminishes in importance and the increase in labor drops off quickly. For the spending shock, the productivity effect only manifests as physical and human capital arrive. For this reason, the peak increase in the supply of hours occurs 20 years after the shock. The fifth panels show the labor input as defined in equation (13). This measure comprises both human capital and hours worked, and its dynamics reflect the combined dynamics of these inputs.

We consider consumption in the sixth panels. For the spending shock, the increased tax yields an immediate decrease in consumption. The dynamics causing an eventual increase in human and physical capital allow an eventual increase in consumption. The effect on consumption becomes positive by year 10, and peaks in year 25. With the productivity shock, consumption instead increases immediately. This effect increases over a few periods as the capital stock builds up and then begins to decrease. Though not shown here, results are little changed in an environment with only distortionary taxes when we consider the impact of a productivity shock. With no change in spending, only small changes in taxation are required to maintain a balanced budget. Results change more when we consider the impact of a shock to government education spending since increases in distortionary tax rates are required to fund the spending. The difference is most pronounced in the effects on capital, investment, and labor hours in the first several periods after the shock. As mentioned above, investment and the labor input fall on impact and capital falls early on in response to lower investment. However, over the medium to longer term, the impact of each is largely just scaled down and each has a peak at nearly the same time as in the lump sum case.

2.7.4. Life cycle effects of education spending shocks. Thus far, we have focused on the dynamic responses of various economy-wide aggregates. These responses comprise the underlying dynamics of particular cohorts. We now consider these underlying dynamics along two dimensions: the dynamics of particular periods of adulthood as they are traversed by sequential cohorts, and the life cycle dynamics of particular cohorts as they traverse adulthood. Figure 1 above shows life cycle features of a representative cohort in the steady state. Figure 5 instead considers both dimensions of cohort dynamics following a shock to education spending.

The first panel considers human capital. The solid black curve shows the effect on human capital for 41 successive cohorts as they pass through the first period of adulthood. The point associated with year 0 shows the increment to human capital from a period t spending shock for those workers in their first period of adulthood in period t. Since the human capital of this cohort was determined by prior spending, the increment is zero. The point associated with year 1 is slightly positive. Students in their first period of adulthood one period subsequent to the shock benefit from increased spending over a small part of their schooling. They experience a small increment in human capital relative to what it would have been absent the shock. The human capital increment to succeeding cohorts in their first period of adulthood increases each year until period 12, when those who were in kindergarten at the time of the shock reach adulthood. The point labeled A represents that cohort in their first year of adulthood. The point associated with period 40 shows the human capital of the future youngest adults 40 years after the shock.

The dashed red curve shows similar information, but for agents in their tenth year of adulthood. Note that there is no change in human capital for workers in their tenth year adulthood at the time of the shock; the dashed curve is at zero in the initial period. Human capital of this cohort is determined by spending 10 and more years prior. Similarly, the human capital of those in their tenth year, 1 year after the shock, has no change in their human capital since this is determined by spending 9 and more years prior. Not until today's oldest students are in their tenth year of adulthood do we see an increase at this stage of adulthood. At this point, the effect on human capital is small, since these are the students for whom only 1 year of education is influenced by this spending. The effect on subsequent cohorts grows until today's kindergarten students are in their tenth year. This is represented by the point labeled B. In a similar fashion, the dotted blue curve shows the effect on workers in their twentieth years of adulthood. In each case, there is no change until today's oldest students arrive at the stage under consideration. The effect is largest when today's kindergarten students reach the stage as indicated by point C. The points A, B, and C then map out the effect on period t



Notes: The solid black curve in each panel shows the effect on successive cohorts as they pass through the first period of adulthood. The dashed red and dotted blue lines show these effects as cohorts pass through the tenth and twentieth periods of adulthood. The points labeled A, B, and C correspond to the effect in the first, tenth, and twentieth periods of adulthood for those in kindergarten at the time of the shock, respectively.

FIGURE 5. Life cycle features of responses to an education spending shock.

kindergarten students as they pass through the various stages of adulthood (first, tenth, and twentieth year). Similarly (for example), moving five periods to the left along each curves gives a locus of points mapping out the effect for cohorts 5 years older than period t kindergarten students as that cohort passes through these same stages. Moving five periods to the right along each curves gives analogous life cycle information for cohorts 5 years younger.

The second panel is structured in the same way but shows the effect on labor hours provided. The solid black curve shows that each cohort works more in the first period of adulthood due to the spending increase and that this effect peaks as period t kindergarten students enter the market (point A). The dashed red and dotted blue curves again map out the effect after 10, and 20 years of adulthood and points A, B, and C track the life cycle effects on period t kindergarten students. The pattern is one of a large effect early in life and a smaller, eventually negative effect later. For example, period t kindergarten students work more while young than they would absent the shock (points A and B), and less later in adulthood

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(point C). Given this, the hours increase shown in panel three of Figure 4A is due mostly to changed behavior while young.

The third panel shows the effects of a spending shock on consumption. The labeled points again plot the effect on period t kindergarten students. This cohort consumes more in each period of adulthood than they otherwise would have. The spending shock has different implications for those who are adults in period t. The first point on the solid curve corresponds to consumption by the cohort who is in their first period of adulthood at the time of the shock. The first inflection point on each of the remaining curves shows consumption for this same cohort at 10 and 20 years of adulthood. For this cohort, consumption is lower in each of these periods of adulthood. More generally, though not shown, we find that these agents have lower, or nearly lower, consumption in each period of adulthood and that sufficiently older cohorts have strictly less consumption in each period. Current workers pay a higher tax to support education but have no change to their own human capital. They stand to benefit only through adjustment to wages as the capital stock rises. However, this adjustment proves insufficient to offset their loss. As such, one effect of the shock is an inter-generational transfer to students at the expense of initial workers and retirees.

The final panel considers savings. The labeled points show that the life cycle savings effect on today's kindergarten students and the nearby cohorts is positive in each period of adulthood. The effect starts out small early in adulthood and peaks mid-career. This increased savings reflects a desire to smooth the consumption associated with increased income. Moving to the left along each curve, we see that for sufficiently older cohorts, savings is lower in each period than otherwise, reflecting the overall decrease in net lifetime income. An implication is that the eventual capital build-up shown in the second panel of Figure 4 is primarily the effect of positively impacted cohorts saving more for retirement later in their life.

3. EMPIRICAL METHODOLOGY AND EVIDENCE

3.1. Empirical Methodology

We now turn to an empirical investigation consistent with this theoretical perspective as it pertains to aggregate output. In particular, we examine the empirical response to shocks to public education expenditures. Our empirical methodology for isolating these shocks is related to the broader literature that identifies the output effects of government spending shocks using SVAR. This literature has generally employed *time-series SVAR* methods to identify innovations to government expenditures. Time-series SVAR methods, however, require data with a long time dimension. Because long time series for noninterpolated quarterly data on government spending and taxes are typically not readily available for most countries, a number of papers have recently employed annual data in time series SVAR models. The resulting shorter time series due to the use of annual data can reduce statistical power and raise degrees of freedom concerns. To address this

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challenge, some papers, notably Beetsma et al. (2006, 2008), Ravn et al. (2012), and Ilzetzki et al. (2013), have identified fiscal policy shocks using *panel* SVAR methods.

This section investigates the impact of shocks to state and local public education expenditures on state output using panel SVAR models. Our empirical methodology is most closely related to Atems (2019) who estimates the output response to a shock to total state and local government spending using quarterly data for the period 2005:I–2015:II. Other US state-level studies that employ panel SVAR models similar to ours include Barcellos (2010), who studies the dynamics of immigration and wages; Calomiris et al. (2013), who study the relationship between house prices and foreclosures; Atems and Jones (2015) on how shocks to income inequality impact state output; and Feasel et al. (2017) on the relative effects of demand and supply shocks on US state-level unemployment and output.

The use of state-level data, however, raises some concerns about how to appropriately address issues related to cross-state spillovers and parameter proliferation. The above mentioned state-level studies impose the assumption that states are independent, as a way to sidestep this parameter proliferation problem. That approach, clearly, overlooks concerns about cross-state spillovers. Carlino and DeFina (1998) group states into regions and estimate regional impulse responses, thereby assuming that states within regions respond to shocks in a similar manner. While this approach captures heterogeneity, it implicitly assumes cross-regional independence. Nakamura and Steinsson (2014) estimate how a government spending increase in one region relative to another impacts output within the region. They control for the effects of aggregate/national shocks by including time fixed effects in their regressions. Another approach, employed by, among others, Davis and Haltiwanger (2001), and Owyang and Zubairy (2013) is to specify a block-recursive VAR that includes an aggregate block and a state-level block. The state-level block contains observed variables specific to a particular state, and the sum of the same variable in the remaining states. For example, Owyang and Zubairy (2013) include personal income in state i, employment in state i, the sum of personal income in all other states excluding personal income state i, and employment in other states, minus employment in state i. The idea is that including the same economic indicators observed in other states captures cross-state spillovers.

In this section, we apply the approach of Owyang and Zubairy (2013) to control for cross-state spillovers, with some modifications. Similar to Owyang and Zubairy (2013), we include national macroeconomic variables in our VAR model to control for common across-state effects. We also include the sum of output in all other states to control for cross-state output effects of a shock to education spending. However, unlike Owyang and Zubairy (2013) who estimate a separate VAR model for each state, thereby potentially suppressing the cross-state spillover effects of national macroeconomic shocks, we employ a panel VAR model. We describe the panel VAR model in more detail below.

3.1.1. The panel VAR model. Consider the reduced-form panel VAR model:

$$X_{it} = A(L)X_{i,t-1} + \psi_i + U_{it}, \tag{15}$$

where $i = 1, \ldots, 51$ denotes states (and Washington DC), $t = 1, \ldots, T$ indexes years, $X_{it} = \left[X_{1t}\ X_{2it} \right]'$, and $U_{it} = \left[U_{1t}\ U_{2t} \right]'$. The vector $X_{1t} = \left[g_t\ r_t\ o_t \right]'$ is a three-dimensional vector of US macroeconomic variables. In this vector, g_t denotes the Ramey (2011) military news variable to control for shocks to federal (defense) government spending; r_t denotes the federal funds rate to measure monetary policy; o_t refers to percentage change in oil prices to capture the effects of oil price shocks. This block, which we refer to as the US macroeconomic block, is included to control for common across-state effects.[14] The second block, $X_{2it} = \left[b_{it}\ e_{it}\ y_{-it}\ y_{it} \right]'$, is the US state-level block. Here, b_{it} is the state and local government budget surplus expressed as a percentage of GSP, e_{it} represents state and local government education expenditures, y_{it} denotes state output, and y_{-it} is the sum of output across all states excluding state i. The reduced-form residuals in each block are $U_{1t} = \left[U_t^g\ U_t^r\ U_t^o \right]'$ and $U_{2it} = \left[U_{it}^b\ U_{it}^e\ U_{-it}^y\ U_{it}^y \right]$. L represents the lag operator; $A(\cdot)$ is a matrix polynomial in L; and ψ_i are time-invariant state-specific effects. We set $L = 4$ as determined by the Akaike Information Criterion.[15]

Following convention, education spending and output enter the VAR in logarithms of real per capita values. Output and education spending are likely nonstationary in log-levels. Our estimation methodology is most suited for stationary variables around a constant mean. Estimating the model with output and education in log-levels may imply a distortion of the time series by subtracting a time-varying mean. The VAR implicitly uses the constant to fit a transient component, conditional on the first p lags, where p is the lag order of the model (Sims (2000)). When output and education spending are expressed in first differences, the impulse responses revert to zero quite quickly, as expected. Note that a similar problem arises in purely time series VAR models, yet much of the VAR literature on the output effects of shocks to government spending express the variables in logarithms (See e.g. Blanchard and Perotti (2002), Gali et al. (2007), Mountford and Uhlig (2009), Ramey (2011), Ilzetzki et al. (2013), Gnimassoun and Mignon (2016), Khan and Reza (2017), and Ramey and Zubairy (2018)). To maintain comparability with the relevant literature, we estimate the VAR models in this paper with output and education spending in log-levels.

The combination of fixed effects and lagged endogenous variables in equation (15) results in the well-known Nickell bias. To overcome this problem, we apply the Helmert transformation (Arellano and Bover (1995)) to remove the fixed effects. This procedure expresses the variables in deviation from their forward means by subtracting from each variable, the mean of all its future observations. Specifically, let $\overline{X}_{it} = \sum_{s=t+1}^{T_i} \left(\frac{X_{is}}{T_i - t} \right)$ and $\overline{U}_{it} = \sum_{s=t+1}^{T_i} \left(\frac{U_{is}}{T_i - t} \right)$ denote the respective forward means of X_{it} and U_{it}. Subtracting $\overline{X}_{it}$ and $\overline{U}_{it}$ from X_{it} and U_{it},

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respectively, transforms them to $\widetilde{X}_{it} = \sqrt{\frac{T_i-t}{T_i-t+1}}(x_{it}-\overline{X}_{it})$ and $\widetilde{U}_{it} = \sqrt{\frac{T_i-t}{T_i-t+1}}(U_{it}-\overline{U}_{it})$, where $\widetilde{X}_{it}$ and $\widetilde{U}_{it}$ are the Helmert-transformed variables.

Rewriting equation (15) in terms of the transformed variables yields:

$$\widetilde{X}_{it} = A(L)\widetilde{X}_{i,t-1} + \widetilde{U}_{it}. \quad (16)$$

This forward mean differencing transformation preserves the orthogonality between transformed variables and lags of the untransformed variables (Love and Zicchino (2006)), providing moment conditions that allow for the estimation of the panel VAR model using the Generalized Method of Moments (GMM). Alvarez and Arellano (2003) show for a first-order autoregressive model with individual effects that this GMM estimator based on the Helmert transformation is consistent when both N and T are large, and $T/N \rightarrow c$ for $0 < c \leq 2$. They perform Monte Carlo simulations with different combinations of values of N and T. Their results for the case with $N = 50$ and $T = 50$ (see Table II of their paper) are of particular relevance to us, since $N = 51$ and $T = 52$ (and $T/N = 1.02$) in our paper. Even in this case, they find that the bias of the GMM estimator is considerably small.

3.1.2. Identification. Let B_0 be a non-singular matrix that is normalized so that the main diagonal elements are unity. We postulate that the following relationship between the reduced-form residuals and the structural shocks, $\widetilde{\varepsilon}_{it}$, holds: $\widetilde{U}_{it} = B_0^{-1}\widetilde{\varepsilon}_{it}$. Premultiplying equation (16) by B_0 results in the panel SVAR model:

$$B_0\widetilde{X}_{it} = B(L)\widetilde{X}_{i,t-1} + \widetilde{\varepsilon}_{it},$$

where $B = B_0A$. The VAR literature has discussed several approaches for recovering the structural shocks from the estimated reduced-form residuals. These approaches typically impose exclusion restrictions on B_0^{-1}. In this paper, a block-recursive structure is imposed on the contemporaneous relationship between the reduced-form residuals, $\widetilde{U}_{it}$, and the structural shocks, $\widetilde{\varepsilon}_{it}$. The first block, as mentioned previously, consists of US macroeconomic aggregates, whereas the second block constitutes US state-level variables.

The US macroeconomic block contains the variables g_t, r_t, and o_t, in that order. Since our goal is to estimate the effect of state and local education expenditures on state output, the way the variables within this block are ordered is irrelevant for our purposes, as long as they are ordered before education expenditures in the VAR model (Christiano et al. (1999), Beetsma and Giuliodori (2011)). The second block constitutes the US state-level variables, b_{it}, e_{it}, y_{-it}, and y_{it}, in that order. The ordering of the aggregate macroeconomic block before the state-level block reflects the assumption that the aggregate US economy affects, but is not affected by, state economies contemporaneously. Ellahie and Ricco (2017) also estimate VAR models with national macroeconomic variables ordered before state-level variables.

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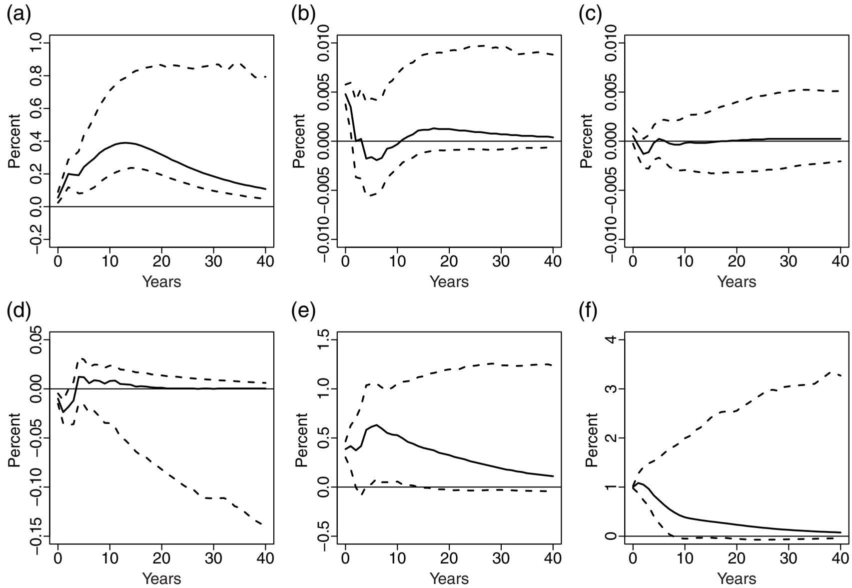
In the US state-level block, we assume that state and local education expenditures respond to changes in the state budget on impact. This block further imposes the restriction that shocks to education spending affect output contemporaneously, but that education spending responds to shocks to output with a delay of at least 1 year.[16] Assuming that it takes at least 1 year for shocks to output to affect education expenditures is reasonable because budgetary appropriations for state and local public spending are made at the start of the year. Therefore, state and local officials are unable and/or unlikely to change public expenditures in response to favorable or adverse changes in the economy within the year, but are more likely to change these expenditures with a lag of 1 year or more. The assumption that government expenditures respond to changes in output with a lag is similar to the identification approach pioneered by Blanchard and Perotti (2002), which has been recently employed by Gali et al. (2007), Beetsma et al. (2006, 2008), and Ilzetzki et al. (2013).

3.1.3. Public education spending multipliers: Definitions. The related literature typically summarizes the output effects of government spending shocks in terms of a multiplier: the change in output due to a one-unit increase in government spending. The magnitude of the spending multiplier may differ considerably across forecast horizons. Consequently, it is instructive to distinguish between two types of multipliers. The first, referred to as the *impact multiplier*, and represented by $m_{1,q}$, measures the change in output q periods ahead caused by the initial movement in public education expenditures (Mountford and Uhlig (2009), Ilzetzki et al. (2013)). This is calculated as:

$$m_{1,q} = \frac{\Delta y_{t+q}}{\Delta e_t} \frac{1}{e/y}, \tag{17}$$

where Δy_{t+q} is the output response to a shock to government education expenditures in period $t+q$, Δe_t refers to the response of public education spending to its own shock in period t, and e/y is the average share of public education spending in output over the sample.

Future fiscal financing adjustments, lags in the implementation of fiscal policy, coupled with the fact that it generally takes time for the impact of spending shocks to propagate through to the economy, implies that focusing entirely on the impact multiplier may be misleading. This is especially the case for government education expenditures because while there might be an initial boost to the economy arising from an increase in demand due to the spending increase, much of the output effects of an increase in education expenditures will occur in the long run. This idea is formalized in the theoretical model outlined above and is consistent with the broader literature on the long-run effects of public education expenditures, in particular, and human capital accumulation, in general. Accordingly, we focus also on the present-value multiplier, $m_{2,q}$, which measures the net present value of the cumulative change in output from the instant of the impulse to public



Notes: Dotted lines are the 95% confidence bands based on Monte Carlo simulation with 1000 replications.

FIGURE 6. Response of output to education spending and other macroeconomic shocks.

education expenditures to q periods after that impulse:

$$m_{2,q} = \frac{\sum_{j=0}^{q} (1+r)^{-j} \, \Delta y_{t+j}}{\sum_{j=0}^{q} (1+r)^{-j} \, \Delta e_{t+j}} \frac{1}{e/y}, \tag{18}$$

where r is the average interest rate over the entire sample. This present value multiplier quantifies the effect of an increase in government expenditures along the entire path of the output response (Leeper et al. (2010)); hence, as $T \to \infty$, this multiplier enables us to gauge the long-run impact of a shock to public education expenditures.

3.2. Empirical Evidence

This section presents the responses of output to a shock of 1% to public education expenditures, and to other macroeconomic variables. In all the graphs, the solid curves are the impulse response estimates, while the dashed curves refer to the 95% confidence bands constructed by Monte Carlo simulation methods with 1000 repetitions. Variance decompositions are also presented in order to assess the quantitative importance of shocks to public education expenditures relative to other shocks.

Figure 6 displays the benchmark impulse response functions of output to a shock to each of the six variables in the VAR model.[17] Our main result of interest

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is depicted in Panel A, which displays the behavior of output following an innovation of 1% to government education expenditures. For completeness, however, we first briefly expound the output responses to shocks to the other variables. We do so in the order in which these variables appear in the VAR. Hence, Panels B to D show the output responses to shocks emanating from the US macroeconomic block. Panel B shows a positive response to a federal (defense) government spending shock, which is statistically different from zero for the first year. This is consistent with findings from other studies. For example, Ellahie and Ricco (2017) find that federal defense consumption elicits a positive, significant but short-lived output response. Zeev and Pappa (2017) find that following a shock to the Ramey defense news variable, aggregate output rises significantly for the first four quarters, after which it becomes statistically indifferent from zero. Consistent with much of the monetary policy literature (see e.g. Christiano et al. (1999), Romer and Romer (1994)), Panel B shows that output declines in response to a contractionary monetary policy shock, although the response is indistinguishable from zero statistically. In Panel D, output declines for the first 4 years in response to an oil price shock. Evidence of a contractionary output response to an oil shock is documented in a variety of VAR-based studies, including, for instance, Bernanke et al. (1997), Herrera and Pesavento (2009), Herrera et al. (2011), Herrera (2018), and Atems and Melichar (2019).[18]

Panels E and F of Figure 6 show how state output responds to shocks originating from the US state-level block. In Figure 6E, output rises significantly in response to a shock of one percentage point to the budget surplus-to-GSP ratio. This positive response is consistent with, for example, Gemmell et al. (2011). Figure 6F shows that output experiences an expansion following its own shock. This is most analogous to the total factor productivity shock in our theoretical model. The expansion is different from zero for the first 8 years.

The key modeling innovation presented in Section 2 is the introduction of a time-release response to government education spending. The model demonstrates that an education spending shock can have both an immediate, short-lived, effect on output and a delayed, longer-lived, effect through human capital. Figure 6A shows that our empirical findings are broadly supportive of this aspect of the model. This figure shows the response of output to a shock of 1% to state and local education expenditures. Output displays double hump-shaped dynamics, which are significantly different from zero at all forecast horizons. On impact, output rises by 0.06%, then reaches its first peak of 0.21% three years following the shock to public education expenditures, after which output temporarily declines. From year 5 onward, output begins to rise again, reaching another peak 13 years out, with an estimated effect of 0.39%. At this juncture, output starts declining steadily, even though the response remains significantly positive throughout.

While these results capture several essential features of the model, there are noteworthy differences. In our theoretical model, the full stimulus effect of increased expenditures occurs immediately, while in our empirical results, the

TABLE 1. Impact and present value education spending multipliers at various horizons

Multiplier	Year 0	Year 1	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	Peak (year)
Impact	**1.02**	**2.31**	**4.49**	**6.76**	**7.08**	**5.88**	**4.49**	**3.43**	**2.59**	**1.99**	**7.22 (13)**
Present value	**1.02**	**1.72**	**3.59**	**5.40**	**6.84**	**7.67**	**8.09**	**8.32**	**8.43**	**8.50**	**8.50 (40)**

Notes: Numbers in parentheses are the horizons corresponding to the peak response. Boldface numbers indicate that 0 is outside the region between the 95% confidence bands.

contemporaneous effect is statistically significant but quantitatively small and takes several periods to be fully realized. This may reflect institutional delays from spending increases, which we do not model. Also, as discussed in Section 2.7, spending increases yield an immediate increase in investment and labor hours worked in our model. Both of these adjustments cause output to increase and may be slower in the actual economy due to time-to-build features of the capital stock and labor market rigidities. Moreover, the lower two curves in Figure 2D show that the extent of the immediate impact is smaller with distortionary taxes. The results also differ in the size of the response, with peak empirical responses larger than those in the calibrated model. However, as seen in Figure 2, peak responses in the model are sensitive to several parameters of the model. In addition, adding features to the human capital accumulation process could increase this effect. For example, K-12 spending tends to increase college enrollment (Jackson et al. (2016), Hyman (2017)). Adding this feature, then, could amplify the results. Adding a complementary private input could yield a further amplification. However, our baseline parameterization with a succinct modeling of human capital is sufficient to demonstrate that observed empirical impulse responses are consistent with human capital as a long-run propagation mechanism.

Using the definitions in equations (17) and (18), and assuming a government education expenditure share of output of 5.4% (the average government education expenditure share over our sample period for all 50 states and DC), Table 1 summarizes the impact and present value multipliers at various horizons. By definition, the two multipliers are equal in period zero, the instant the impulse to public education expenditures occurs. At this point, output rises by \$1.02 in response to an additional dollar of public education spending. Focusing first on the impact multiplier, output reaches a peak effect of \$7.22 after 13 years and then declines thereafter. The present value multiplier, on the other hand, builds over time, such that a cumulative one dollar increase in public education expenditures results in an increase in output by \$8.50 at the 40 year horizon. Notice, as well, that the estimated multipliers are significantly different from zero at all forecast horizons.

The quantitative importance of shocks to public education expenditures for output is assessed by a decomposition of variance analysis. Table 2 reports the

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TABLE 2. Percentage contribution of macroeconomic shocks to variability in output

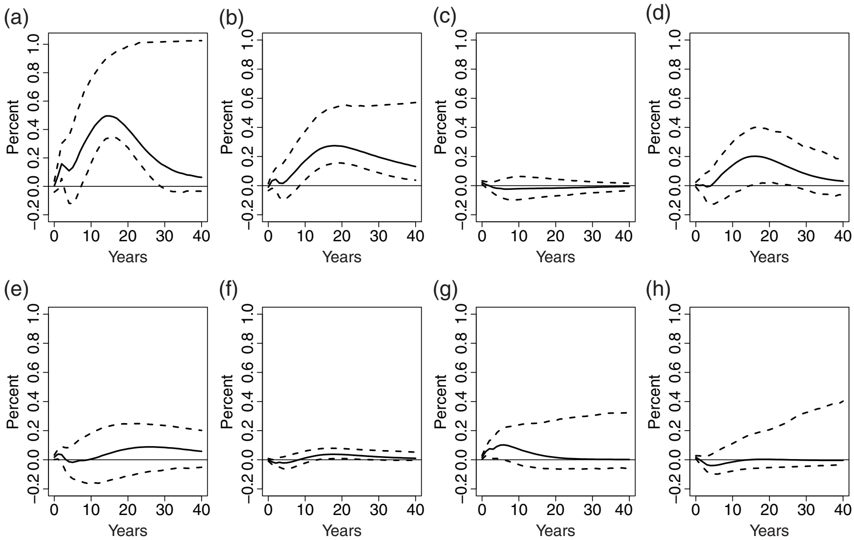
Horizon	Education spending	Federal spending	Monetary policy	Oil price shock	Budget surplus	Output shock
1	0.31	2.35	0.05	0.42	2.46	75.24
5	2.91	0.78	0.12	1.09	3.20	73.36
10	8.04	0.68	0.09	0.94	6.05	67.30
15	15.04	0.59	0.08	0.89	7.15	61.74
20	19.96	0.61	0.07	0.80	7.54	58.04
25	22.63	0.63	0.07	0.75	7.76	55.99
30	24.04	0.65	0.07	0.73	7.88	54.89
35	24.82	0.65	0.07	0.71	7.94	54.28
40	25.26	0.66	0.08	0.71	7.97	53.94

Notes: The percentage of k-step-ahead forecast error variance of output due to public education expenditures and macroeconomic shocks are based on the structural panel VAR model described in text.

percentage of the h-step-ahead forecast error variance of output attributable to education spending and other macroeconomic shocks. The table implies that in the short run, shocks to state and local public education spending explain a small proportion of the unpredictable movements in state output. They explain less than 1% and 3% of the variability of output at horizons one and five, respectively. The explanatory power of the shocks, however, increases with the forecast horizon. At the 40 year horizon, over 25% of the variance of output is attributable to innovations to education expenditures. The bulk of the evidence, nonetheless, suggests that shocks to output itself are primarily responsible for the majority of the variability in state output at both short and long horizons.[19]

At first glance, the estimated multipliers in Table 1 may seem large relative to estimated spending multipliers in the literature. However, estimates of large multipliers are not uncommon. For example, Giordano et al. (2007) estimate a multiplier that starts at about 1.2 and peaks at 3 after six quarters; Auerbach and Gorodnichenko (2012) estimate a government spending multiplier that reaches a value of over 2.25 after 5 years; and Auerbach and Gorodnichenko (2013) find multipliers as high as 6.69 after 3 years during recessions. Given the considerable evidence that government spending shocks have persistent output effects (Gali et al. (2007), Ramey and Zubairy (2018)), we conjecture that spending multipliers reported in the literature are likely to be larger at forecast horizons as long as ours.

Moreover, our results are not directly comparable to many previous studies due to differences in focus and data. This paper focuses on the effects of education expenditures, rather than aggregate government expenditures, as in much of the literature. The multiplier effect of total government spending is likely to be smaller because total government spending also consists of unproductive government expenditures. While public education spending enhances productivity, unproductive government expenditures have no direct production function effects



Notes: Dotted curves are the 95% confidence bands based on Monte Carlo simulation with 1000 replications.

FIGURE 7. Responses of output to various government spending shocks.

beyond the initial stimulus impact. Thus, the inclusion of such expenditures in total government expenditures is expected to dampen the magnitude and persistence of education (and other productive) expenditures. As pointed out by Baxter and King (1993), and Ramey (2011), this is one of the central tenets of neoclassical predictions about the effect of (productive versus unproductive) government expenditures.

To investigate this hypothesis, Figure 7 presents the output responses to shocks to total state and local government spending, as well as to seven subcategories, namely public administration, construction, health and hospital, transportation, public protection, sanitation, transportation, and public utilities. In Figure 7A, output rises by 0.03% in response to a 1% increase in government spending. The response turns significant in year 3, reaching an initial peak of 0.16% in that year. From then on, output declines and turns insignificant until year 8 when it starts rising significantly again, arriving at another peak of 0.50% in year 15. This positive response lasts until year 30, becoming insignificant thereafter. Hence, while qualitatively the output response to a shock to total state and local government spending is similar to the response of output to a shock to state and local education spending reported in Figure 6A, at no instant is the output response to an education spending shock insignificant. Assuming a government spending share of 17.2% (average total government expenditure share of output over the entire sample), the impact (present-value) multipliers of total government spending at the 0, 1, 10, 20, and 40 year horizons are, respectively, 0.17 (0.17), 0.44 (0.30),

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2.25 (1.23), 2.35 (2.19), and 0.52 (2.41). These multipliers are much smaller than those for education spending in Table 1. Yet the magnitudes of the total government spending multipliers are consistent with those in the literature on the output effects of state and local government spending shocks (see e.g Ellahie and Ricco (2017) and Nakamura and Steinsson (2014)).

This qualitatively similar, but quantitatively smaller multiplier effect is to be expected since total expenditure contains education spending, and potentially other productive items, as well as items that are unproductive. Panels B to H of Figure 7 show the impulse responses of output to innovations of 1% to each of the seven subcategories of government spending. At short horizons, the output response is positive and significant in most cases, consistent with a stimulative effect of government spending. Except in Panels B and D which show that two other government expenditures—public administration and public health—have persistent effects similar to education expenditures (although the magnitude of the effects are smaller), the effect of the stimulus generally dies out relatively quickly.[20] This finding that the effects of other government expenditures are smaller and short-lived is in line with the neoclassical view (Barro (1989)) which suggests that while an unproductive government spending increase may stimulate the economy in the short run, the overall impact of such a spending increase is a negative wealth effect, which crowds out private consumption and investment (Leeper et al. (2010)). We note that the behavior of the multiplier effect may also be due in part to factors outside our model. In particular, other types of expenditures may have a delayed and positive effect on output as suggested by Panel B. Moreover, Leeper et al. (2010) find evidence of a similar response to government investment. This is suggestive that a richer model with a productive role for additional components of government spending could be a useful refinement to our current work. Overall, though, our results are suggestive that the output response to a shock to total state and local expenditures is substantially driven by the response to education spending, consistent with a time-release aspect to education expenditures.

We perform several sensitivity analyses to ensure that our empirical results are robust to several potential concerns. For example, our empirical methodology imposes the restriction that the underlying structure of the VAR is homogeneous across states. This assumption, however, may be violated if a particular state or set of states is driving the results. To verify that there are no outliers or that our results are not driven by a particular state, we estimate 51 separate panel VAR models, leaving out one of the 51 states/DC each time. The output response to education spending (and all other responses) remains largely unchanged. These results are available upon request. In an unpublished appendix, we further demonstrate that our results are not sensitive to the ordering of the variables in the VAR. In addition, we show that the key result with respect to the impact of education spending on output remains unchanged regardless of the measures of federal government spending shocks, monetary policy shocks, and oil price shocks. This robustness is consistent with our theoretical model, which emphasizes a unique role of human capital as a long-run propagation mechanism.

4. CONCLUDING REMARKS

The paper builds a stochastic overlapping generations model to show that government education spending can have long-lasting effects on output. The model tracks the dynamics of the economy as it responds to an increase in education spending. We consider a case with many generations and a stochastic setting with temporary shocks to government education expenditures, non-education government expenditures, and productivity. In the model, all shocks have qualitatively similar contemporaneous impacts and short-run dynamics; temporary productivity shocks increase output directly and each type of government expenditure shock has a stimulative effect on output. The stimulative effects of non-education government expenditures diminish relatively rapidly. The government education expenditure shock, however, has a secondary time-release effect on output through human capital accumulation.

The paper then estimates the impact of state and local education expenditures on state output within a framework that captures the time series facts about state economies. Specifically, we use US state-level data for the period 1963–2016, and a panel SVAR methodology. Identification is achieved by assuming that shocks to government education expenditures affect output contemporaneously, but that shocks to output only affect education expenditures with a lag. Our empirical results are consistent with the theoretical model developed in the paper. In particular, we find that (*i*) the response of output to a shock to government education expenditures displays marked double hump-shaped and persistent dynamics, with peak effects occurring 3 and 13 years after the shock to education spending; (*ii*) non-education government expenditures, unlike education expenditures, generally have little to no effects on the economy beyond their initial stimulus effects; (*iii*) shocks to education spending explain a relatively large proportion of the long run variability of output. These findings highlight a distinctive role of education spending for short- and long-run fluctuations in output.

NOTES

1. https://www.cbpp.org/research/an-update-on-state-budget-cuts.
2. See the recent meta-analytic review by Churchill et al. (2017) and the citations therein.
3. See for example Barro and Sala-i-Martin (2004), Devarajan et al. (1996), and Blankenau et al. (2007).
4. Examples include Blanchard and Perotti (2002), Beetsma et al. 2006; 2008, and Khan and Reza (2017).
5. Gemmell et al. (2011) discuss in greater detail the disparate short-run and long-run approaches to evaluating the effects of fiscal policy on growth.
6. Examples include Glomm and Ravikumar (1998), Eckstein and Zilcha (1994), Kaganovich and Zilcha (1999), Blankenau and Simpson (2004), Su (2004), and Arcalean and Schiopu (2010).
7. http://hdr.undp.org/en/content/mean-years-schooling-males-aged-25-years-and-above-years.
8. https://www.bls.gov/opub/mlr/2001/10/art2full.pdf.
9. https://www.cdc.gov/nchs/fastats/life-expectancy.htm.
10. https://www.cdc.gov/nchs/products/databriefs/db21.htm.

11. https://data.worldbank.org/indicator/FR.INR.RINR?end=2017&locations=US&start=1961&view=chart.

12. https://www.bls.gov/opub/mlr/2001/10/art2full.pdf.

13. Specifically, we use Dynare v4.5.7 (Adjemian et al. (2011)). Our code is available upon request.

14. The variables in this block do not vary by state, hence the absence of the "*i*" subscript.

15. Key findings are generally robust to the lag order. In particular while the magnitudes of the output responses differ somewhat based on the lag length, we find that the contemporaneous and long-run effects are always significantly different from zero. These results are available from authors upon request.

16. Note that there are two components of output: output in state i, y_{it}, and total output in other states excluding state i, y_{-it}. This distinction is not relevant for the validity of our identifying assumptions.

17. We estimate a VAR model with seven endogenous variables, but we leave out the response of output to a shock to output in other states as this response is neither important for our purposes, nor qualitatively different from the response of output to its own shock.

18. In an unpublished sensitivity analysis, we consider alternative measures of aggregate government spending, monetary policy, and oil shocks. For example, in some specifications, we measure government spending using total federal government expenditures. In others, we use the Ramey and Shapiro (1998) dates, or the defense news shocks identified by Zeev and Pappa (2017). Similarly, we consider, as measures of oil shocks, the Hoover and Perez (1994) dates, Hamilton (1996) "net oil price increase" (NOPI), and an oil price increase measure as in Mork (1989). We also experiment with the ratio of the log of nonborrowed reserves to the log of total reserves as the measure of US monetary policy. Our baseline results do not change.

19. The sum of the variance decompositions across shocks (row sums) is not equal to 100 because the table omits the h-step-ahead forecast error variance of output attributable to shocks to output in other states.

20. While public administration expenditures have a "time-release" impact similar to education expenditures, we do not discuss this result in detail, as these expenditures are not the focus of the paper.

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APPENDIX A: DATA DESCRIPTION AND SOURCES

To estimate the SVAR models, the paper uses annual data from 1963 to 2016 for all 50 US states and DC. The data come from several sources.

A.1. DATA ON STATE AND LOCAL GOVERNMENT EXPENDITURES AND REVENUES

Data on state and local government revenues and expenditures come from the State and Local Government Finance Division of the US Census Bureau. Fiscal policy data are not available for the years 2001 and 2003 for state and local governments (only available for state governments), so we omit these years. Therefore, we have 52 years of annual data for all 50 states and DC, giving a sample of about 2652 observations. To express the variables in real terms, all nominal variables are deflated by the Consumer Price Index: Total, All Items for the US (CPI), collected from the Federal Reserve Economic Database (FRED), and further divided by total state population to express in per capita terms.

Our measure of public education spending is total state and local direct government expenditures on education. That is, the sum of state and local Elementary and Secondary Education expenditures (K-12), Higher Education expenditures, and Other Education spending. Figure A1 plots the time series of the logarithm of public spending in education by state. There is an overall upward trend in most states. However, episodes of declining education expenditures are apparent across most states in the 1970s and 1980s, and after the 2009 financial crisis and subsequent recession. Figure A.1, therefore, seems to suggest that there are common trends in state and local public education expenditures.

A.2. DATA ON STATE OUTPUT

State output is measured by the gross state product (GSP) per capita. GSP data are obtained from the Regional Economic Accounts (Bureau of Economic Analysis). The GSP data are also converted to real per capita values by deflating by the CPI and state population.

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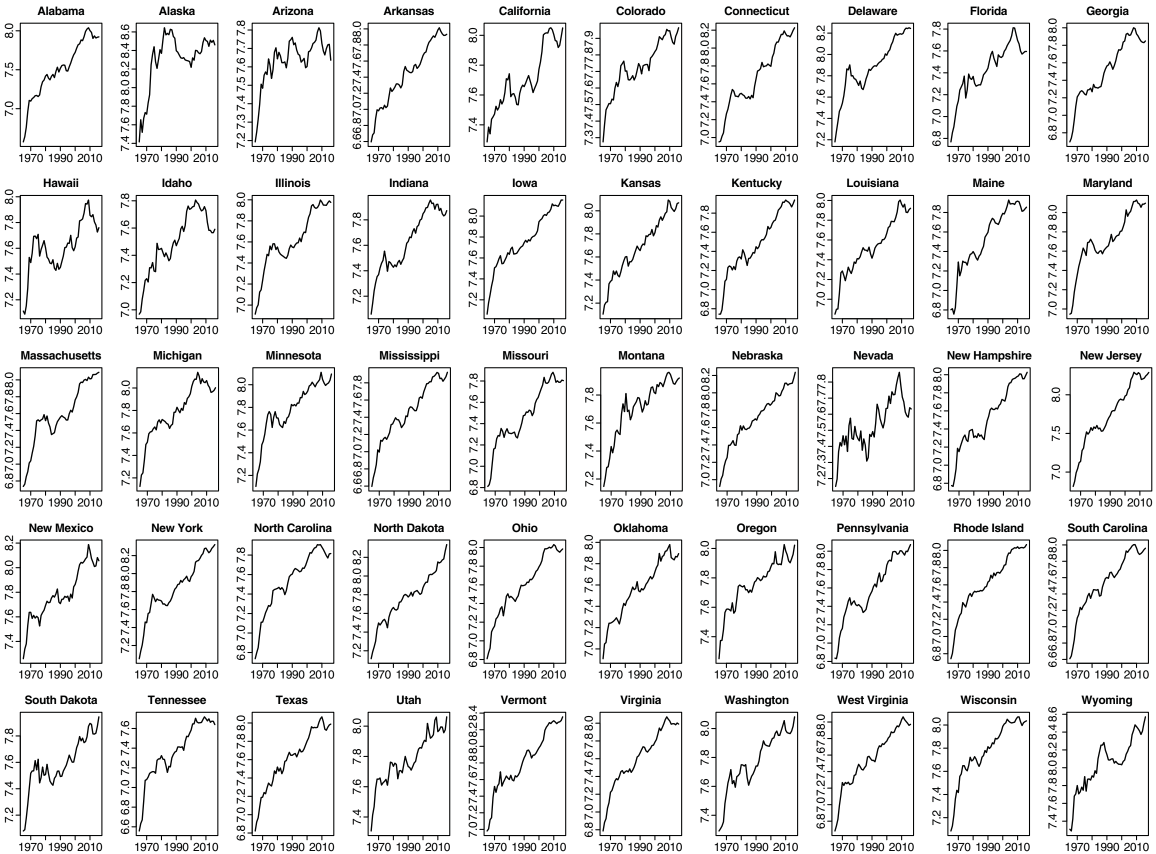

FIGURE A1. Real per capita public education spending (in natural logarithms) by state: 1963–2014.

A.3. DATA ON NATIONAL MACROECONOMIC VARIABLES

The VAR models also contain aggregate macroeconomic variables that impact state output. In particular, we consider measures of federal government spending, oil shocks, and US monetary policy. We use, as our measure of federal government spending, an updated measure of Ramey's (2011) defense news variable, collected from her website at https://econweb.ucsd.edu/~vramey/research.html#data. We measure oil price shocks using the West Texas Intermediate crude oil prices (deflated by the CPI), collected from FRED. As the measure of US monetary policy, we use the federal funds rate, collected from FRED.

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