

Three Essays in Microeconomics

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Abstract

Economical decision making is complicated by uncertain and changing consequences. This dissertation looks at three unique scenarios – market structures that encourage the harvest of damaging invasive species, the decisions of undocumented immigrant in the face of immigration enforcement, and long-term student outcomes when risk protections are extended.

First, I expand a dynamic harvesting model to include the damages incurred by the presence of an invasive species to understand the unique scenarios that exist from invasive species that have consumptive value. I find that these have unique “tipping points” where a manager can optimally push the species to eradication. In cases where eradication is not optimal, the manager can use species “rebranding” to encourage harvests better than bounties placed on harvests.

Second, I examine how undocumented immigrants respond to the threat of deportation by contrasting daily attendance among undocumented Hispanic, documented Hispanic, and white students. I find that undocumented Hispanic students are acutely responsive to the roll-out of a state immigration enforcement law, with large spikes in absenteeism on days when the law overcomes court challenges, and increased withdrawals from school immediately following the law clearing federal court. These laws seem to resonate more than Immigration and Customs Enforcement (ICE) operations, as the former affects absenteeism, withdrawal and proxied concerns (internet search behavior) while ICE enforcement does not.

Last, I analyze the differential responses of undocumented students to risk protections extended by DACA (Deferred Action for Childhood Arrivals). I extend the literature by examining the effect of the introduction of DACA in 2012, as well as the effect of its suspension in 2017. Student reactions in terms of disciplinary infractions, absences, and

grades shed light on the extent to which uncertainty affects human capital development and engagement with school.

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Chapter 1

Carp, Cows, and Kudzu: Eradication of Invasive Species via Markets

Introduction

During the British rule of colonial India, the colonial government wanted to rid the city of venomous cobras. To do this, the government instituted a bounty on the head of every cobra to allow market forces to push the species towards local extinction (eradication). Instead, enterprising citizens began to farm the cobras to net the bounty reward, thus increasing the number of total cobras in Dehli. The government scrapped the program thereafter, which worsened the colonial government's original problem exponentially as farmers released the now worthless cobras into the streets. While this seems like an archaic parable, the same management strategies continue to be implemented today. In Florida, a per-snake bounty has been placed on the invasive population of Burmese Pythons threatening the Everglades. ¹ In Georgia, a per-tail bounty has been placed on the feral hog herds that threaten livestock, and fragile ecosystems. ² In the Caribbean and Gulf of Mexico, various subsidy packages have been initiated to push Lionfish into the fish consumption market, to protect local fisheries and tourism (Morris Jr and Whitfield, 2009). Lastly, several states in the Ohio/Mississippi river

¹Taken from <https://www.aol.com/article/news/2017/05/16/florida-government-pays-bounty-hunters-to-capture-pythons/22093415/>

²Taken from: <http://www.foxnews.com/story/2008/02/29/major-pig-czar-seeks-out-destroys-fort-benning-feral-hogs.html>

drainage have proposed or implemented subsidy programs to nudge silver and bighead carp into export markets.³ All of these programs attempt to use market-based solutions to push an invasive species towards extinction- but is that theoretically possible? Can internalizing the damages created by a population make extinction more likely when the harvest brings tangible rewards to those doing the harvesting?

Three research questions are of specific interest when examining invasive species that have a market value (“marketable invasive species”): a) what conditions must be present for socially optimal eradication of an invasive species? b) how does the presence of consumer demand for a species influence an optimal bounty? and c) how effective would rebranding have to be to eliminate the need for a bounty? To examine these dynamics, we expand the optimal harvesting models of [Clark \(1976\)](#) and [Lewis and Schmalensee \(1977\)](#) to include the damages incurred by the presence of an invasive species. Importantly, we use the critical stock level where a social planner would optimally push the species to eradication as a foundation for our policy analysis.

Relevant Literature

Invasive species have emerged as growing issue for government and private entities alike. But even pinning down what defines an invasive species can be difficult and controversial. Ecologists have proposed a simple definition of: organisms not native to the biomes in which they reside. But, cattle, largemouth bass, earthworms and others fit this definition in the United States and there is no public or governmental interest in the removal of such species. Thus, we work closely with the definition offered by [Shogren and Tschirhart \(2005\)](#) with a special focus on (4) :

- (1) [An invasive species] must be imported to an area where it is not native;
- (2) it must be introduced into the wild: (3) it must become established with a self-sustaining population; and (4) it must be a pest which means that it must trigger costs to humans or ecosystems that outweigh any attendant benefits.

³Taken from Courier Journal article “Asian Carp Fishermen Hook New Markets <http://www.courier-journal.com/story/news/local/2015/03/14/asian-carp-catching-area-businesses/70297264>

Importantly, these damages are being quantified on a large scale. [Pimentel et al. \(2005\)](#) find that of 50,000 invasive species present in the United States, their cumulative damages amount to \$137 billion in economic and environmental damages. Another useful index is the United States' governmental outlays for the abatement of invasive species, which in 2000 was over \$556 million dollars ([Lovell and Stone, 2005](#)). Some of these outlays are the sheer labor cost to physically remove invasive species ([Simberloff, 2008](#); [Simberloff et al., 2005](#)). And these costs result from not only the direct effect of the invasive species presence (such as direct timber loss due to Ash Borer beetles) but also from the indirect effects in the system. Indirect effects range from lost ecosystem services, decrease in agricultural yields, and smaller harvests ([Gren, 2008](#)). For example, the slump of Black Sea anchovy harvests in Turkey were a result of predation from non-native comb jellyfish on the local stock of anchovies, and thus created an economic cost borne by the local fishing fleets ([Lovell and Stone, 2005](#)). In the United States, 400 of the 958 endangered species listed under the Endangered Species Act are at risk due the biological competition or predation of invasive species ([Pimentel et al., 2005](#)).

While the ecological literature on invasive species is well-developed, economists have recently began to close the gap between the two fields' work. One major branch is optimal decision making during the spread of invasive species. [Olson and Roy \(2002\)](#) show that optimal eradication decisions rely not only on the biological growth rate of the invasion, but also the severity of the damage caused by the invasive species. Specifically, if the invasive population is small with a slow growth rate, and the marginal elimination costs are less than the damages, complete eradication is optimal. However, if the same dynamics are at play, but the marginal elimination costs are higher than the damage cost, it is optimal to let some of the invasion remain. Now if the invasive species has an explosive growth trend, it is optimal to swiftly eradicate a population before it begins that growth trend, which would be reflected in eradication costs. [Olson and Roy \(2003\)](#) also show that optimal policy may involve periodic control, when the marginal costs of control are sensitive to invasion size rather than the control itself. [Eiswerth and Johnson \(2002\)](#) found that concrete interpretation of optimal choices were heavily sensitive on the parameters used, necessitating a clear link between ecological research and economic predictions for invasive species. Property rights and the

spatial dispersal of the invasive species matters for optimal control and elimination strategies (Fenichel et al., 2014). In addition to the modeling of these interactions, several eradication case studies have been added to the literature which follow shocks such as climate to biological control strategies (Gosling and Baker, 1989; McConnachie et al., 2003)), with Burnett et al. (2006) modeling the actual dynamics of eradication and control in Hawaii. It is important to pause and consider the results of this literature in light of our “marketable” invasive species. Where this literature postulates an eradication cost, it could be translated as “harvest cost” as the social planner reclassifies this species from pest to commodity. Additionally, the revenue gained from the sale of the invasive could reduce overall welfare losses generated from the damages created by the same species. Thus, if we extrapolated the results of this stream of literature upon marketable invasive species, the possibility of eradication might be *less* likely as the species is seen less as a pest and more of a commodity.

Another closely related branch of research revolves around the dynamics of optimal extinction in natural resources. Starting with Clark (1976) it was shown that the maximization of the present value of the stock, when the discount rate was sufficiently high comparative the species growth rate would yield an “optimal extinction,” where profit-maximizing agents would drive the stock to absolute extinction. Clark (1976) used this simple model to explain crashes in whale stocks and others when the standard economical models of the time would have predicted benevolent management of sustained yields. Lewis and Schmalensee (1977) expanded upon this finding by including a non-convexity in the growth function of the stock, to account for the fact that many species will be pushed to extinction by the constraints of minimum-viable population thresholds (i.e. if a stock is driven to 1 remaining member, and 2 are needed for reproduction, a non-zero value stock can push towards extinction). With this key addition, Lewis and Schmalensee (1977) show that even at low discount rates, or large, non-convex fixed-costs, extinction of a stock may be indeed optimal. Cropper et al. (1979) add to this discussion by showing that another important aspect is the initial stock size, even when the benefits of a stock are nonlinear function of the harvest rate. While their results mirror those of Clark (1976) they find optimal extinction only resides in the cases where initial stock sizes are small. Specifically, the relationship between discount rate and growth rate on the viability of optimal extinction

is more reliant on stock size, when the selling price of the harvest is inversely related to the actual harvest rates. [Farrow \(1995\)](#) applied this model directly to economic extinction history to compare the results of the demise of the passenger pigeon as compared to the near-demise of the American bison. [Clark and Lamberson \(1982\)](#) also examined this in the context of pelagic whaling, given the profitability and known extinction constraints. All of these models examine commercially valuable species, which have no “damages” in their own right. If we again pivoted these models into our marketable invasive species story, the eradication of the species might become *more* likely, as the social planner would take into account the damages these species incur, while also acknowledging the establish dynamics of optimal extinction. The disparity between the this extrapolated result, and the previous stream of invasive species management presents an opportunity for research. Since literature on optimal eradication of invasive species points to a lessened chance of eradication once a species achieves commodity status, and conversely, the literature on optimal extinction of stocks points to an increased chance of that eradication once damages are accounted, an integrated model is needed.

Importantly, our research is different on a few other points. First, we are examining species that were intentionally placed in a home country for economic purposes (whether as pets, agriculture, aquaculture, or biological control) instead of organisms that “hitchhiked” via trade. This is different from some of the seminal work done by [Lovell and Stone \(2005\)](#), [Costello and McAusland \(2003a\)](#), [Costello et al. \(2007\)](#), [Costello and McAusland \(2003b\)](#), and [Mérel and Carter \(2008\)](#). Secondly, instead of focusing on the spacial or uncertain aspects of invasions ([Sharov \(2004\)](#), ([Wilén, 2007](#); [Saphores and Shogren, 2005](#)), we take a generalized view to draw conclusions on the possibility of extinctions. Thirdly, the species we research have marketable attributes unlike many invasive species. For instance, Emerald Ash Borers (insects) and silver carp (fish) both disrupt their respective host ecosystems and can impose high costs on their respective economies. But where the Emerald Ash Borer has no market value of its own, the silver carp actually has a seafood market around it in its native range (East Asia) and thus has begun an unusual invasive-species-to-export-commodity loop in the United States.

Our discussion of these dynamics are as follows: first we outline a general framework where a species has marketable value and social damages, with specific focuses on comparing socially optimal to private market outcomes. Next, we extend this framework to calibrate a model around the silver carp invasion to show the bioeconomic dynamics of this current invasion. Then we contrast two policy choices to push a private market towards a socially-desirable harvesting level. Lastly, we draw general conclusions on the general state of consumable invasive species and the policies around them.

Harvesting A Marketable Invasive Species

We extend the standard dynamic model of efficient harvest of a renewable resource in two ways. First, we assume the renewable resource inflicts a cost to society to reflect the economic and ecological damage created by invasive species. Second, we allow for optimal management to both harvest and restock the population to address the common concern that building a market around a pest could create incentives to exacerbate the spread of the species.

Let $x(t)$ represent the physical stock of the marketable invasive species and $y(t)$ be the amount harvested ($y > 0$) or restocked ($y < 0$) in time t at discount rate ρ . The aggregate growth function $G(x(t))$ shows the net growth of the population (growth less mortality). The resource constraint shows that the change in the stock level is equal to the growth function less the harvest or the additions from restocking. To incorporate restocking, we follow (Rondeau, 2001) and restrict $y(t) \geq y_{min}$ where $y_{min} < 0$. In our application to invasive species, y_{min} may represent the maximum amount of invasive species restocking allowed by a regulatory authority.

The net benefits are represented by $\pi(t)t = \pi(x(t), y(t))$, where we assume $\pi(0, x) = 0$, $x \geq 0$, $\pi_x(0, x) = 0$, $\pi_x(y, x) > 0$, and $\pi_{yx} > 0$. Our model is immediately differentiated from standard harvesting models by $D(x)$, which is the damage function of the presence of the invasive species.

$$\max_y = \int_0^\infty [\pi(y(t), x(t)) - D(x(t))]e^{-\rho t} dt$$

Subject to the stock's growth, harvest/stocking bounds, and initial conditions:

$$\frac{\partial x}{\partial t} = \dot{x} = G(x(t)) - y(t) \quad (1.1)$$

$$y_{min} \leq y \quad (1.2)$$

$$x(0) = x_0 \quad (1.3)$$

$$\mathcal{H} : \pi[x(t), y(t)] - D(x(t)) + \lambda(G(x(t)) - y(t)) \quad (1.4)$$

The current value Hamiltonian in Equation 1.4 allows us to form the Lagrangean expression Equation 1.5, where the Kuhn-Tucker multiplier μ constrains the y space above some arbitrary minimum.

$$\mathcal{L} : \pi[x(t), y(t)] - D(x(t)) + \lambda(G(x(t)) - y(t)) + \mu(y - y_{min}) \quad (1.5)$$

The necessary conditions for the solution of this system would be,

$$\pi_y(x, y) - \lambda + \mu = 0 \quad (1.6)$$

$$\dot{\lambda} = \lambda(\rho - G_x) - \pi_x + D_x \quad (1.7)$$

With initial condition $x(0) = x_0$, the transversality condition follows:

$$\lim_{t \rightarrow \infty} e^{-\rho t} x(t) \lambda(t) = 0 \quad (1.8)$$

Additionally, the Kuhn-Tucker conditions require:

$$\mu \geq 0; \quad y \geq y_{min}; \quad \mu(y - y_{min}) = 0 \quad (1.9)$$

These conditions guarantee that interior solutions will be characterized by $\mu(t)$ equaling 0. Or, Equation 1.6 can be updated to:

$$y = \begin{cases} y_{min} & \text{if } \pi_y(y_{min}) < \lambda \\ y^* & \text{if } \pi_y(y^*) = \lambda \end{cases} \quad (1.10)$$

If we set $\mu = 0$, Equation 1.6 shows a familiar relationship in resource management – the marginal net benefit of harvesting must equal the marginal value of an additional unit of the invasive species. Yet, if we consider the fact that λ can be positive or negative, two possibilities emerge. In the case where $\lambda > 0$, the standard interpretation fits, where the net benefit(profit) must equal the shadow value. However, if $\lambda < 0$ the species is a pest, where harvesting is undertaken to mitigate the damages from the species. Importantly, multiple equilibria may be present, due to the non-convexity present in the Hamiltonian. In further sections, we will turn to numerical applications to verify the solutions presented. Equation 1.7 describes how the rents associated with harvesting the marketable invasive species evolve over time. Even with large marginal damages, rents can rise so long as marginal growth is smaller than the discount rate and the stock effect (π_x) is small. Under those conditions, the social planner harvests more to increase the scarcity value.

Taking the time derivative of Equation 1.6 and using our updated results in 1.10 we can define the evolution of the harvest isocline as:

$$\dot{y} = \frac{\lambda(\rho - G_x) - \pi_x + D_x - \pi_{yx}\dot{x} - \dot{\mu}}{\pi_{yy}} \quad (1.11)$$

To analyze steady states, we take $\dot{\mu} = 0$ and $\dot{x} = 0$ and examine the case where restocking at y_{min} isn't the optimal solution (again $\mu = 0$). This reduces Equation 1.11 to an updated version of the “Fundamental Equation of Renewable Resources” (FERR). This includes the damages created by the marketable invasive, and shows our optimal steady state values of x and y will push the rate of return for the resource to equal the rate of return in the economy.

$$\rho = G_x + \frac{\pi_x - D_x}{\pi_y} \quad (1.12)$$

However, there are potentially two externalities associated with marketable invasive species that suggest a private market will not achieve this social optimum. The private bioeconomic equilibrium depends on a tension between the rents and the damages created by the invasive species (Figure 1.1). In a private market, resource owners may ignore the damages their resource stocks (i.e., the invasive species) inflict on others since invasive species control is a weak-link public good. The public good nature of invasive species control suggests an equilibrium with lower harvest and higher stocks of the invasive species. Explicitly if Equation 1.7 is at the steady state level, then ignoring damages ($D_x = 0$) will lead to an upward shift in the $\dot{\lambda} = 0$ isocline, as reflected in Figure 1.1.

$$\lambda = \frac{\pi_x - D_x}{\rho - G_x} \quad (1.13)$$

Alternatively, no individual may have exclusive property rights to harvest the invasive species leading to market entry that eventually dissipates all rents. In this invasive species variant of the tragedy of the commons, harvests are higher than the social optimum leading to stocks that are lower than the social optimum. As shown in Figure 1.1, this is also the case where the invasive species is most likely viewed as a pest at steady state ($\lambda_{ss} < 0$). Due to these countervailing externalities, the private bioeconomic equilibrium may result in a stock of the invasive species that is higher or lower than the social optimum. The greater the exclusivity of harvesting rights, the more likely the private market will result in an inefficiently large stock of the invasive species. However, these two extreme outcomes do frame our private bioeconomic equilibrium.

Will Markets Eradicate?

Clark (1976) characterized the concept of “optimal extinction,” where an efficient market pushes a species to extinction. By maximizing the net present value of the stock, even a sole owner might harvest a stock to extinction if the growth rate were sufficiently low and the discount rate sufficiently high (Clark, 1976). If this model were expanded (included here in the appendix), we would see that the inclusion of damages would lower the steady state stock level and extinction could still be an optimal harvest strategy.

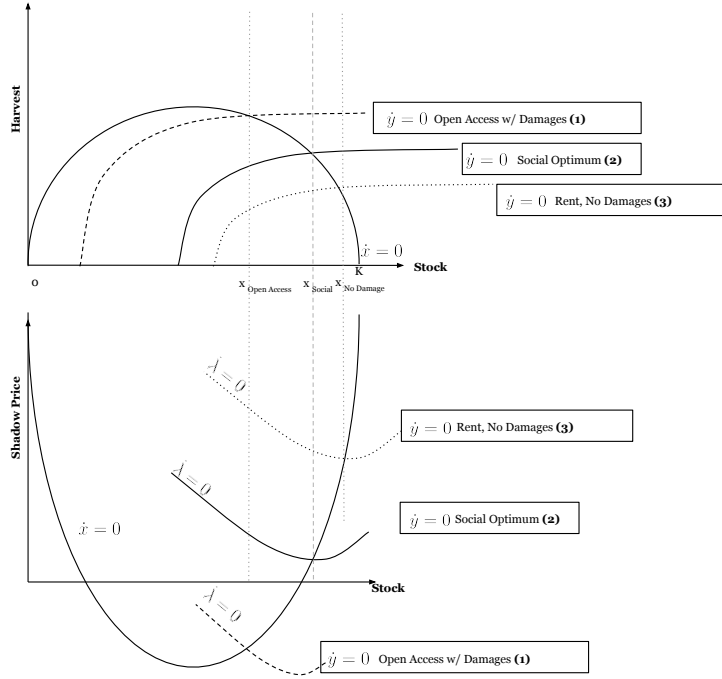


Figure 1.1: Bioeconomic equilibrium for a marketable invasive species under sole owner and private market. The first panel shows the relationship between harvest and stock level, while the second shows shadow price and stock level. The socially optimum stock level is centered by the “push” of rents and “pull” of damages.

While extinction is still an optimal strategy with damages included, the [Clark \(1976\)](#) model relies crucially on a simple profit function ($y*(price - cost)$), without a minimum viable population, and without the possibility of restocking. To get closer to an analytic solution, we note the similarities between our model and that of [Lewis and Schmalensee \(1977\)](#) who proposed a critical stock level where there is a minimum viable population for the stock. The inclusion of the minimum viable population is an important step towards generality, so that every case that leads to eradication is visualized. This is crucial for our modeling since eradication is the goal itself (in other harvesting exercises, a simpler logistic growth function might suffice). [Cropper \(1988\)](#) updated [Lewis and Schmalensee \(1977\)](#) to define the tipping point where a sole owner would chose between a sustainable harvesting strategy and exhaustion of the resource based on the initial condition of the stock. For very low sizes of stock, with commercially valuable attributes, extinction is an economically optimal solution. For larger population sizes, sustainable harvests dominate as the key strategy. Importantly, this initial stock level can exceed the minimum viable population meaning that there are cases where exhaustion of the resource would be warranted. We present a brief sketch below based on these stylized dynamics in [Figure 1.2](#).

As plotted earlier, $\dot{\lambda} = 0$ plots the co-state isocline and $\dot{x} = 0$ represents the zero growth isocline. The space is bounded by the minimum viable population (x_{min}) which assures eradication and the carrying capacity of the population, x_{max}). Two paths plot different strategies: (S) to the sustainable harvest steady state x^* and (E) to eradication x_{min} or (0). x_0 represents the initial stock level in the population. When damages are unrecognized, the only optimal harvesting path is to the sustainable harvest equilibrium. However, once damages are incorporated, the eradication harvest path may dominate.

Therefore, $x_{critical}$ represents the the largest initial condition of the stock condition where eradication is still an optimal strategy. Any condition above this, the sustainable harvesting strategy dominates. Comparatively, the inclusion of damages will, in this stylized case, move the $x_{critical}$ upward. Crucially, as noted by [Cropper \(1988\)](#), the [Lewis and Schmalensee \(1977\)](#) model relies on harvesting ceasing once profits are dissipated. But, in the case of a marketable invasive species, harvesting could hypothetically continue if the damages were large enough, as the sole owner recognizes the harvesting costs as damage abatement expenditures. Thus,

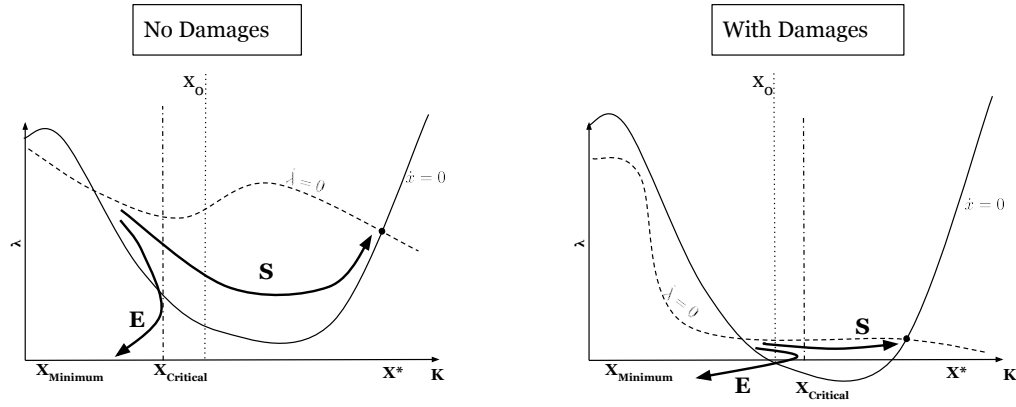


Figure 1.2: Phase diagram showing optimal extinction path and sustainable harvest path. The solid and dashed lines represent the isoclines of the system, while the arrows represent paths to equilibria

we must turn to numerically verifying and typifying the existence and movement of a critical stock level.

Will Markets Exacerbate an Invasion?

Markets for invasive species clearly create incentives for harvests, which could limit the propagation of the species. Yet, markets could also create incentives to conserve and perhaps exacerbate invasive species' spread. The unintended consequences of attempts to control the Indian cobra are a cautionary tale. In our model, market forces will exacerbate an invasion when $y^* < 0$. In that case, a strategy that maximizes the net benefits of the invasive species involves reintroducing (i.e., stocking) the invasive species.

We start by analyzing the conditions under which an optimal steady state will be characterized by restocking. Since a steady state is defined by $G(x_{ss}) = y_{ss}$, a steady state characterized by restocking will only occur when the steady state is below the minimum viable population: $G(x_{ss}) < 0$. In this case, a small amount of restocking keeps the population below the minimum viable population while also keeping the invasive species from going extinct. For a steady state stock larger than the minimum viable population, $G(x_{ss}) > 0$ necessitating a harvest from that stock to maintain a steady state. Thus for restocking to be an optimal strategy at steady state, the steady state stock must lower than the minimum viable population.

To determine how much restocking is optimal in this scenario, we return to the FERR:

$$\rho = G_x + \frac{\pi_x - D_x}{\pi_y} \quad (1.14)$$

When the stock is slightly less than the minimum viable population $G_x > 0$. Thus, a steady state with a stock slightly less than the minimum viable population and a relatively small amount of restocking would be characterized by a marginal stock effect that is less than the discount rate: $\rho > (\pi_x - D_x)/\pi_y$. The marginal stock effect measures the relative impact of the fish stock on profit. The larger the marginal stock effect, the more harvesting costs are sensitive to the level of the stock. For instance, if marginal harvesting costs are independent of the stock of fish ($\pi_x = 0$), the marginal stock effect is negative due to the marginal

damages inflicted by the stock. Note that $\pi(y < 0) \leq 0$ due to the cost of restocking but $\pi_y(y < 0) \geq 0$ since a lower amount of restocking is less costly. As the optimal steady state moves close to 0 $G_x < 0$. A steady state with a stock less than the minimum viable population but close to 0 and larger amounts of restocking would be characterized by a marginal stock effect larger than the discount rate: $\rho < (\pi_x - D_x)/\pi_y$.

From this analysis we can conclude that restocking will be larger and more problematic under the following conditions:

- The discount rate is small. (Open access makes this less likely.)
- The effect of the stock on harvesting costs is large (π_x is large).
- The marginal damage from the invasive species is small when stocks are small (i.e. $D_x(x < \underline{x})$ is small).
- Restocking is costless such that $\pi_y(y < 0) = 0$.

Definitive statements about the possibility of temporary restocking along the optimal path to the steady state are more elusive. The possibility of optimally restocking an invasive species when it is optimal to eradicate that species seems unlikely. However, it certainly seems plausible that it could be optimal to restock an invasive species along the path to the interior steady state. For instance, it may be optimal to push a newly discovered but not yet established invasive species toward establishment $x > x_s$ if that invasive species will generate significant profits at higher population levels. This outcome is a variant of the case of intentional introductions of invasive species. However, since most invasive species are discovered after they have become established, the possibility of temporarily restocking along the optimal path may be less likely in practice.

Model Species: the Silver Carp

In the 1970's Silver Carp (*Hypophthalmichthys molitrix*) escaped agricultural ponds where they been placed for biological control, and established populations in the Mississippi River drainage. Thanks to an fast growth rate, and a feeding pattern well-suited for the eastern

half of the United States, these carp have extended their range to most the major river systems and are currently poised to invade the Great Lakes. This outcome is predicted to have major impacts on the local fish stocks, namely the lucrative salmon fisheries of the Great Lakes (importantly – where one non-native fish is out-competing another non-native fish). Additionally, these carp have begun to out-compete native populations in the rivers they exist in. Nearly 80 percent of the commercial fishermen on the Illinois River left the market after carp eliminated most native buffalo-carp fish and catfish, fish species that were crucial to economic success.⁴

To counter this growth, many states have implemented subsidy programs to incentivize the harvest of non-native carp. Kentucky has agreed to subsidize up to 15 cents per pound of the fish,⁵ while Illinois and other states are subsidizing the processing plants to lower the production overhead, while Mississippi combined this strategy with an export-focused model.⁶ These examples allow us to examine the results of our model in the context of actual policies. Using a simple fisheries model, we will parameterize our model and look at the predicted effects proposed above.

The Model

We organize a parameterized model inclusive of a linear demand function, cost function of fishing, growth model (with a minimum-viable population and carrying capacity included), and damage function. The variable x is the stock of carp, y is amount of carp harvested and λ is our current value costate variable. We then look at two market structures reacting to the invasive species: private fishermen and a socially optimal planner.

⁴Taken from the National Wildlife Federation’s article: “Alien Invasion: A Great Lakes Dilemma” <https://www.nwf.org/News-and-Magazines/National-Wildlife/Animals/Archives/2007/Alien-Invasion-A-Great-Lakes-Dilemma.aspx>

⁵Taken from Courier Journal article “Asian Carp Fishermen Hook New Markets” <http://www.courier-journal.com/story/news/local/2015/03/14/asian-carp-catching-area-businesses/70297264>

⁶Take from CBS News article “A money-making idea: Exporting Asian carp to China” <http://www.cbsnews.com/news/a-money-making-idea-exporting-asian-carp-to-china/>

Our demand function is integrated over harvests, where parameters a_0 and b_0 shift and rotate our demand curve, respectively.

$$\int_0^{y(t)} a_0 - b_0 y$$

Our cost of harvesting function follows, where a_1 and a_2 represent the actual costs of harvest such as fishing technology, processing, and other costs needed to bring fish to market. The parameters b_1 and c represent the costs created by the size of the fish population itself, namely the effort and time it takes to search and locate the schools of carp.

$$(a_1 y + .5a_2 y^2 + b_1 x + .5c x^2)$$

Next is our critical depensation growth function, where ψ is the carp's growth rate, ($\psi/\epsilon = \bar{x}$, the carrying capacity of the carp population) and $\underline{x}$ the minimum viable population for a population of carp to survive.

$$-\psi x \left(\frac{x}{\bar{x}} - 1 \right) \left(\frac{x}{\underline{x}} - 1 \right)$$

Lastly, our damage power function is a simple relation between stock size x , damage parameter z , and the power component j .

$$zx^j$$

Private optimal harvesting of established invasive species

In the example of invasive silver carp populations, it would be plausible that fishermen would not fully take into account the damages that carp cause in the ecosystem. Instead of internalizing the externality, they would react to market forces (here: demand and cost functions) and ignore the damages. Thus, our model for private harvesters would have fishermen maximizing harvests, respective of the associated costs.

$$\max_y \int_0^T a_0 y - a_1 y - b_1 x - \frac{a_2 y^2}{2} - \frac{b_0 y^2}{2} - \frac{c x^2}{2} \quad (1.15)$$

This would be then be placed in our private optimal harvest market Hamiltonian

$$H : a_0 y - a_1 y - b_1 x - \frac{a_2 y^2}{2} - \frac{b_0 y^2}{2} - \frac{c x^2}{2} - \lambda \left(y + \psi x \left(\frac{x}{\underline{x}} - 1 \right) \left(\frac{\epsilon x}{\psi} - 1 \right) \right) \quad (1.16)$$

with Optimal Conditions

$$a_0 - a_1 - \lambda - a_2 + b_0 y = 0 \quad (1.17)$$

$$b_1 + c x + \lambda \left(r + \psi \left(\frac{x}{\underline{x}} - 1 \right) \left(\frac{\epsilon x}{\psi} - 1 \right) + \epsilon x \left(\frac{x}{\underline{x}} - 1 \right) + \frac{\psi x \left(\frac{\epsilon x}{\psi} - 1 \right)}{\underline{x}} \right) = 0 \quad (1.18)$$

$$- y - \psi x \left(\frac{x}{\underline{x}} - 1 \right) \left(\frac{\epsilon x}{\psi} - 1 \right) = 0 \quad (1.19)$$

For simplicity all of our parameter estimates are converted into a per-1,000-fish unit. For instance, a_0 represents the choke price for 1,000 fish. We use the current mean willingness-to-pay estimate for carp fillets from [Varble and Secchi \(2013\)](#), combined with the average weight of a silver carp *and* the fillet percent yield of a carp from [Sahu et al. \(2014\)](#). We can then trace out a linear demand curve using the elasticities found in ?. Additionally, we can get a rough idea of our growth parameters λ and ϵ as well as the carrying capacity K from estimates by [Sass et al. \(2010\)](#). While some fisheries managers studying carp assert population reductions of 40% would drive the species to collapse, we included a more conservative minimum viable population of 6.25% of K ([Tsehay et al., 2013](#)). We use a discount rate of 0.05. Problematically, very little is known about the harvest costs or functional parameters for U.S. carp so our values in a_1 a_2 b_1 and c reflect lower cost estimates of harvest, inclusive of limited stock effects, low harvest cost, and low search costs.

Inclusive of these parameter values, we can display the dynamics of our system with phase diagrams.

Table 1.1: Parameters Used in Carp Analyses

<i>Economic Parameters</i>						
a_0	b_0	r	a_1	a_2	b_1	c
59,629,005	42,898,565	0.05	4,250	2,500	-50	7
<i>Ecological Parameters</i>						
ψ	ϵ	$\underline{x}$	K	z	j	
0.1	.00125	5	80	.05	2	

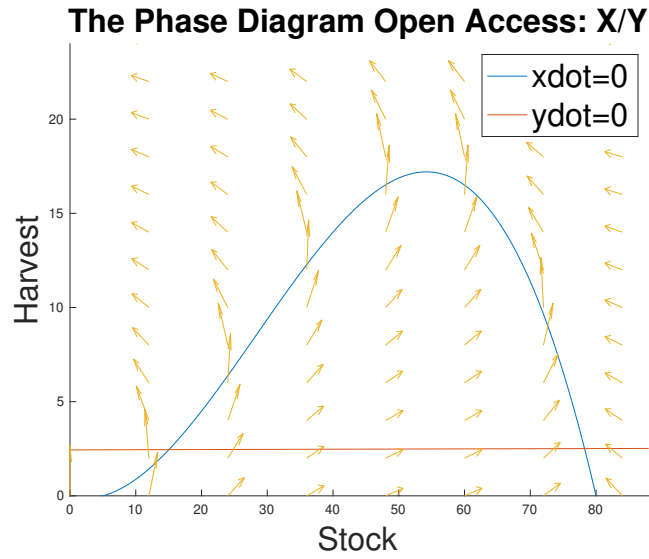


Figure 1.3: Phase diagram of stock, and harvest. Open access scenario ($\lambda = 0$) showing the harvest and stock isoclines at the two equilibria of the system. Small arrows present the motion of system trajectories.

Figure 1.3 shows the dynamics of harvesting a carp population *without* the damages of the population included. In this simple example, the $\dot{x} = 0$ isocline reflects the ecological growth of the species between its $\underline{x}$ of 5 and carrying capacity of 80. The $\dot{y} = 0$ isocline shows our harvesting dynamics, which is, unsurprisingly, a low harvest level, at our saddle path equilibrium solution at 2.6.

With our dynamics in hand, we can move on to a more specific analysis. In the above results, we can think of the model of carp fishermen and stocks without damages accounted for as simple representation of the “private” market interactions for carp. Without damages accounted for, the stock is treated as a commodity and is harvested towards the stable steady state. Later, we will term the model of carp fishermen and stocks *with damages accounted for* as a more “socially optimum” market interaction, where a benevolent social planner internalizes the damages from silver carp (biodiversity impacts, ecosystem alterations, etc.) to influence the optimal harvesting of carp.

Clearly, socially optimal steady state stock levels will be different from to the private steady state, thus the question is how to move the former to the latter. This becomes the antithesis to the classic “tragedy of the commons” problem. Instead of having a market failure where the private market harvests *more* than the sole owner would, we have sub-optimal harvesting.

Social optimal harvesting of established invasive species

Now we put an optimal planner over the fishery and maximize the net present value of the stock respective of harvesting costs and damages created by the invasive carp.

$$\max_y \int_0^T a_0 y - a_1 y - b_1 x - \frac{a_2 y^2}{2} - \frac{b_0 y^2}{2} - \frac{c x^2}{2} - z x^j \quad (1.20)$$

Thus our Hamiltonian is...

$$H = a_0 y - z x^j - a_1 y - b_1 x \frac{a_2 y^2}{2} - \frac{b_0 y^2}{2} - \frac{c x^2}{2} - \lambda \left(y + \psi x \left(\frac{x}{\underline{x}} - 1 \right) \left(\frac{\epsilon x}{\psi} - 1 \right) \right) \quad (1.21)$$

With Maximum Principle Conditions ...

$$a_0 a_1 - \lambda - a_2 b_0 y = 0 \quad (1.22)$$

$$b_1 + c x +$$

$$z j x^{j-1} \lambda \left(r + \psi \left(\frac{x}{\underline{x}} - 1 \right) \left(\frac{\epsilon x}{\psi} - 1 \right) + \epsilon x \left(\frac{x}{\underline{x}} - 1 \right) + \frac{\psi x \left(\frac{\epsilon x}{\psi} - 1 \right)}{\underline{x}} \right) = 0 \quad (1.23)$$

$$- y - \lambda x \left(\frac{x}{\underline{x}} - 1 \right) \left(\frac{\epsilon x}{\psi} - 1 \right) = 0 \quad (1.24)$$

With damages included, we present the phase diagram of harvest and stock levels.

Several equilibria emerge in this updated model shown in Figure 1.4. First, the non-convexities are fully borne in this model and present an asymptote in the harvesting isocline. We have cyclical dynamics around the unstable focus near this where $x = 55.85$. The optimal level of stock around the equilibrium saddle point is 77.83 with harvests at 3.07. These values differ from our private market scenario, where less harvesting is taking place. This moves this species to an opposite realm of “tragedy of the commons” to a stock that is viewed as a pest.

Importantly, these equilibria reflect the fact that pushing the stock to eradication may not be optimal. This stems from the low value placed on carp, and the value placed on damages. Yet the previous analytical results of Lewis and Schmalensee (1977) and Cropper et al. (1979) motivate the existence of some level where the eradication *would* be optimal. Such a level relies crucially on the initial condition of the stock, in addition to consumer demand, harvesting costs, and the non-convexities presented by the species’ growth function. To evaluate such a problem, we turn to another toolkit.

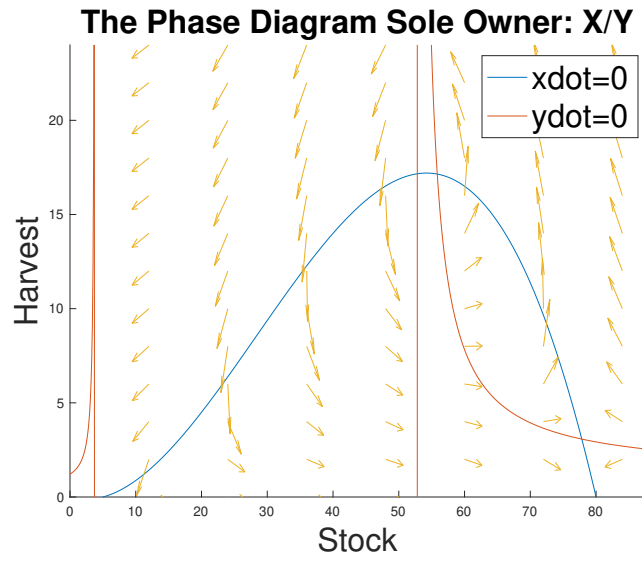


Figure 1.4: Phase diagram of stock and harvest of the stock with damages. Sole owner scenario showing the harvest and stock isoclines at the two equilibria of the system. Small arrows present the motion of system trajectories.

Finding $X_{Critical}$

For the optimal management of the resource, a social planner must choose between typically two population levels: the consistent positive harvests scenario referenced above and the elimination of the stock (extinction/eradication). Whereas [Clark \(1976\)](#) was able to show this a simple analytical framework, our bioeconomic model prevents such analysis. Instead, we use TomLab[®] a pseudospectral solver for optimal control problems, specifically the nonlinear optimization solver, SNOPT[®], within the optimal control framework of PROPT[®]. By introducing the initial stock level as our initial condition, we are able evaluate the optimal value of the net benefits over the entire path going towards the positive steady state or extinction. The simple intuition here is: given an initial stock level of a marketable invasive species would the social planner prefer to harvest it continuously or “cash out” and harvest the stock to extinction? We term the initial stock level $X_{Critical}$ if the optimal harvest strategy flips from consistent harvest to extinction.

Visually, Figure 1.5 shows these dynamics. At initial stock levels below 59 a social planner would harvest the stock to extinction within 30 years. Above that, the planner would allow the stock to increase to the sustainable harvest level. Here our $X_{Critical}$ would be 59.

Now, let’s now examine the dynamics of a carp invasion. First, how do damage level and $X_{Critical}$ interact? Below, we report the results.

First, if there were no damages the sole owner would drive the stock down to lower level at initial conditions less than 59, while increasing the stock to a stable steady state above that point. However, once damages are ramped up, we see the “flip” where a sole owner chooses to drive the species to extinction at initial stocks below 60 and to the stable upper steady state at initial stocks above 59⁷. If damages are pushed up by 50%, $X_{Critical}$ goes up to 61. This increased level reflects the intuition that the sole owner would be willing to extirpate the species (“cash out”) at a higher initial stock level than before. This means eradication is *more likely* once damages are included in the operation. But it should be clear that dramatic changes in the damage allocation for the species does not change the $X_{Critical}$ level dramatically. Additionally, we report how minimum viable population, choke price (i.e.

⁷Again, pinning down damages for carp is difficult, especially the diffuse impacts on ecosystems, boaters, local fisheries.

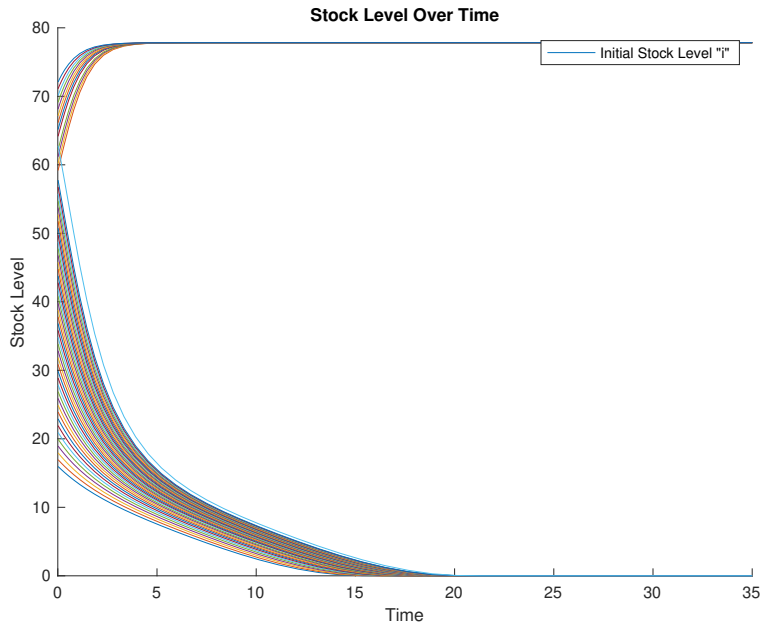


Figure 1.5: Stock Level Representing $X_{Critical}$ where there are non-trivial levels of damages included. $X_{Critical}$ is the initial condition of the stock where a social planner switches from a sustainable harvest strategy to eradication. Each line represents the initial stock of the system, and the subsequent populations levels as time (harvesting) passes. $X_{Critical}$ here equals 59.

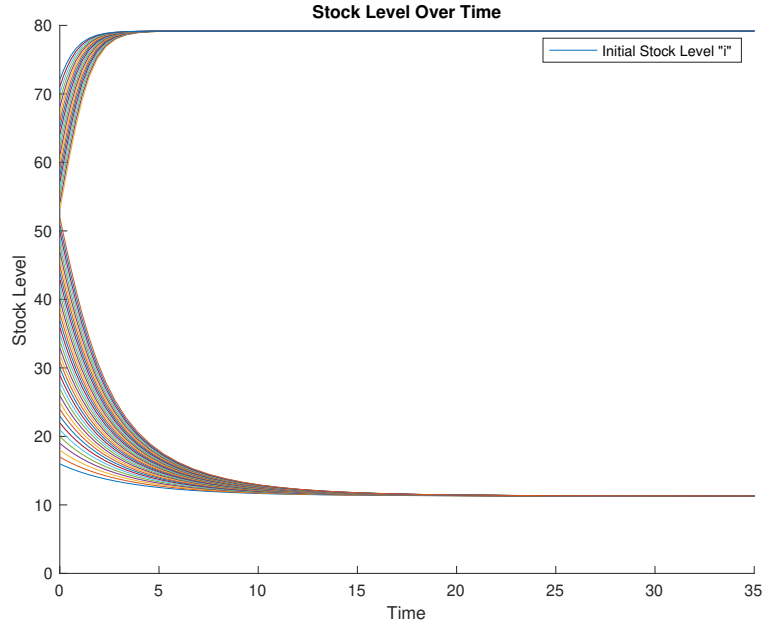


Figure 1.6: Stock Level Representing $X_{Critical}$ where there are no damages included. $X_{Critical}$ is the initial condition of the stock where a social planner switches from a sustainable harvest strategy to eradication. Each line represents the initial stock of the system, and the subsequent populations levels as time (harvesting) passes. There is no $X_{Critical}$ as the sole owner will not harvest past the minimum viable population.

Table 1.2: Parameter Changes and $X_{Critical}$

	$X_{Critical}$
<i>Damages</i> ↑	↑
<i>MVP</i> ↑	↑
<i>ChokePrice</i> ↑	↑
<i>HarvestCosts</i> ↑	↑

demand shifts), and harvest costs influence this $X_{Critical}$ in Table 1.2 . Most these results are intuitive: a larger MVP raises $X_{Critical}$ since the benchmark for crashing the species has gotten closer. A larger choke price means that the demand for the species has shifted out, leading to an increased likelihood of eradication of which the social planner can leverage.

What Can the Social Planner Do?

So far, we have highlighted a) the gap between the optimal level of harvest and the actual private harvest and b) the actual stock level a social planner must reach for eradication to be a viable economic strategy. But what if the initial stock condition is higher than $X_{Critical}$? In that case, eradication is not an optimal management strategy, meaning that the social planner must focus on correcting the market failure of encouraging harvest so that the social and private optima are equal.

Optimal Bounties We begin with a landing subsidy/bounty, the reverse of a landing tax, a well-known fisheries tool. In the case of the silver carp, many states are implementing the former by propping up per-pound-pricing.^{8 9} In our model, fishermen will be paid M for every carp that is harvested. Thus, a private fishermen will see (13) updated to

$$\max_y \int_0^T a_0 y + My - a_1 y - b_1 x - \frac{a_2 y^2}{2} - \frac{b_0 y^2}{2} - \frac{c x^2}{2} \quad (1.25)$$

After solving for optimal harvest, our bounty at the optimum would be \$84.23 (per fish).

⁸Taken from Courier Journal article “Asian Carp Fishermen Hook New Markets <http://www.courier-journal.com/story/news/local/2015/03/14/asian-carp-catching-area-businesses/70297264>

⁹Take from CBS News article “A money-making idea: Exporting Asian carp to China” <http://www.cbsnews.com/news/a-money-making-idea-exporting-asian-carp-to-china/>

$$Bounty^{Opt} = a_0 - a_1 - a_2y - 2b_0y \quad (1.26)$$

Which evaluated at the social planner’s steady state is \$ 35,349.86 of total expenditure. Comparatively, this beats out the damage reduction of \$49,124.79 of going from a private market to social optimal steady states. An important point here is that the “savings” above is driven by the market forces on the species (something that would not be possible with a non-marketable invasive species). Where economically, we’d expect for optimal tax (here, bounty) to equate to the marginal damages, we actual see a mitigation of this effect, meaning the social planner pays less than those damages.

But, we can imagine that as this species enters the American consumption market, demand might shift. More specifically, we might think the choke price might increase, especially if consumers think of consuming carp as an environmentally-friendly pursuit. [Huth et al. \(2016\)](#) found that consumers were willing to pay 10-20% more a pound for invasive species, once they were notified of the species’ damaging effects. Where this seems like a *ceteris paribus* change, it actually sends ripples out into the whole system. Interestingly, if we shift our demand curve (by increasing our choke price (a_0) by 25%), we see that the optimal bounty actually increases to \$85.91. This is due to the fact that private market fishermen would be harvesting more carp already due to increased demand, and thus pushing them to harvest more (to close the gap between social and private steady states) forces them to reckon with stock effects of finding and harvesting fish.

Rebranding Schemes The social planner could start “rebranding” campaigns to stoke domestic demand for a marketable invasive species. For instance, Kentucky is attempting to rebrand silver carp as “Kentucky blue snapper” to attain a higher demand from consumers who recognize snapper as a premium food fish¹⁰. To reflect this in our model, we draw from a very simple model of marketing expenditure on consumer uptake. Specifically, the parameter of operation here is the a_0 , choke price term. As the social planner spends more on rebranding, the choke price will increase. This in tern will shift the demand curve outward.

¹⁰Take from: <https://www.bloomberg.com/news/features/2017-01-19/get-rich-save-the-world-gut-fish>

While we simplify the marketing literature dramatically, we do not assert rebranding-to-demand-shifts being a linear relationship. Instead, we draw from simple statements by [Modis \(2007\)](#) and [Bergemann and Välimäki \(1997\)](#) to trace out a logistic S-curve that captures the simple intuition that a) rebranding can be ineffective and unresponsive to expenditures at first, b) at some tipping point the response is activated (i.e. an inflection point) and c) some diminishing marginal returns to further expenditures. In our exercise, this curve is shaped by c_n the upper bound, c_g the speed at which choke price is responding to rebranding, and c_i the inflection point of when diminishing returns are seen, all of which are added to the original choke price. We bound the curve between the current choke price and the choke price necessary to move the open access steady state to the social steady state(c_n). We then find rb , the rebranding expenditures necessary to offset a bounty of 0 to get the private market to the socially optimal steady state harvest and stock level.

$$a_0 = \frac{c_n}{1 + e^{-c_g*(rb-c_i)}} + a_0(base) \quad (1.27)$$

To estimate this model conservatively, we peg c_g at 0.001, implying there's a slower reaction to expenditures. This ends up implying that the inflection point, c_i becomes the key determinant of the efficacy of rebranding. Analytically, this means rebranding will always be cheaper such that the inflection point (c_i) is

$$c_i < M * (X_{PrivateSS} - X_{SocialSS}) + \frac{\ln\left(\frac{c_n}{\Delta a_0} - 1\right)}{c_g}$$

Stating, rebranding is cheaper when the inflection point is less than the total bounty outlays, given some initial jump after the inflection point. From this relation, we can see that if the responsiveness of consumer uptake is really low ($c_g \simeq 0$) then rebranding will always be cheaper, as long as the infection point of this rebranding effort is less than the total bounty outlays. Of course, if this inflection point occurs *after* rebranding expenditures exceed total bounty outlays, an optimal bounty would be best. In practice, we report a few variations holding consumer uptake speed (c_g) fixed. The reported $a_0(base)$ is the base choke

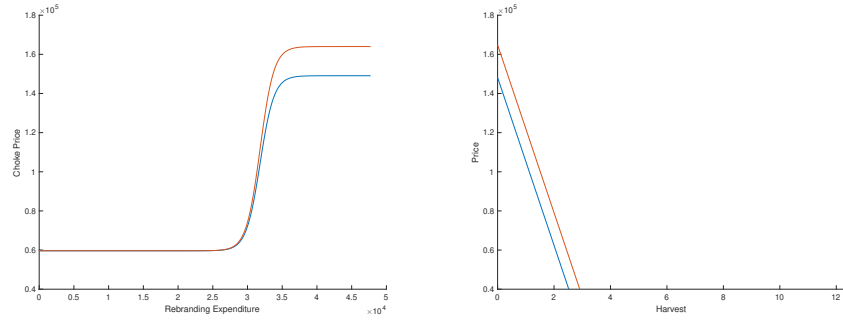


Figure 1.7: Responsiveness of Demand to Rebranding, The left panel plots the choke price as it responds to rebranding expenditures. A secondary plot shows the increased ceiling on responsiveness if consumer demand is more flexible. The right panel reflects how this new flexibility shifts a canonical demand curve outward.

price reported earlier (calculated via the combination of experimental economics WTP for carp and demand elasticities). However, the market settings will yield different productivity.

Concluding Remarks

In our analysis, we have investigated the dynamics of using market mechanisms to push an invasive species towards eradication or to an optimal level of management. We numerically evaluated the idea [Cropper \(1988\)](#) and [Bhat \(1999\)](#) first proposed- within a population growth model there is a specific initial stock level (termed here $X_{critical}$) that acts as a “tipping” point, below which leads to eradication of the stock, while above $X_{critical}$ a sustainable harvesting strategy is seen. Here, we found this tipping point to be around 75% of the carrying capacity of carp. While this might seem like an exciting result to policymakers, many invasive species (such as carp) could be past this point.

If a population is past this $X_{critical}$, then eradication is a sub-optimal strategy, and a manager/planner must focus then on correcting the market failure inherent to the harvesting of this marketable invasive species. Unlike the tragedy of commons problem, we actually need private market harvesters to *increase* their current production levels. We evaluated two policy provisions to make this happen. The first was an optimal bounty, where the planner would pay a per-unit bounty for the harvest of the species. Here we saw that this is an effective strategy, and is cheaper than the outright damage reduction cash value. This is thanks to the dynamics of a demand market being in place. The second policy was “rebranding,” attempts to stoke demand for invasive species consumption. We analyzed this policy by making the choke price within our harvesting model a function of governmental rebranding expenditures. In most cases, this was more cost-effective than an optimal bounty given levels of consumer taste flexibility, and speed of uptake.

This model could be further extended to fit the scenarios where fishermen indiscriminately harvest certain fish species and are able to bring native and invasive species to market. This could be further complicated predator/prey relationships, or general competition for resources. This specified model could be advantageous to policymakers dealing with situations where native and invasive species are intermixed in harvesting situations. Another

extension of this work would include other bioeconomical applications where the harvest technologies used have been explicitly modeled, as well as the population dynamics. This would include merging ecological models as well as specified harvesting parameters into the model to create concrete policy extrapolations. Lastly, applications towards closing the invade-export-invade seem pertinent, especially in the carp scenario. With the aforementioned current policy implementations of market mechanisms to manage populations or incentivize the eradication of wild boar, Burmese pythons, and lionfish populations, clear management modeling is needed to evaluate the efficacy of such policies.

Chapter 2

Immigration Enforcement and Human Capital Investments: Undocumented Student Attendance Under Threat of Deportation

Policies surrounding illegal immigration continue to ignite debates in the public domain and in academic research. To inform this debate, we would like to know how undocumented immigrants interact with institutions at the individual level. Yet, we lack precision even estimating the *number* of undocumented individuals in the U.S. (with a wide span of estimates from 9.3 million¹ to 16.9 million²), let alone individual behaviors around the most popular concerns: labor market competition, resource competition, and externalities. Further, we know little of the individual interactions between undocumented immigrants and the institutions tasked with preventing and controlling illegal immigration (Immigration and Customs Enforcement, ICE).

This study is the first to measure individual responses to immigration enforcement. Specifically, I can identify individuals lacking documentation in a 10-year panel of daily public school attendance records, which are matched to daily immigration enforcement records as

¹Passel et al. (2004)

²Fazel-Zarandi et al. (2018)

well as state legislative changes regarding immigration. Thus, the day-by-day attendance choices of Hispanic students during periods of increased risk can be contrasted between undocumented students, their documented-Hispanic peers, and other students.

These two student groups face dramatically different risks with respect to immigration enforcement, especially deportation, i.e. forced removal from the United States. Documented students (native-born and legal permanent residents) are not subject to deportation.³ On the other hand, undocumented students and their families do not have such protections. Instead, they must account for events that affect their risk of deportation, a process likely started by an ICE arrest. Since anecdotal evidence points to ICE arrests occurring near bus stops and schools,⁴ attendance is explicitly risky for undocumented families. The real costs of deportation – family separation, human capital losses, and trauma – could make the choice of missing school rational and optimal during times of increased risk.

However, individuals must evaluate *which* events affect their deportation risk the most, meaning the salience of risk is a crucial input to attendance choice. Since ICE apprehensions are uncertain in timing and location, undocumented individuals have little predictive power to avoid enforcement.⁵ To examine salience, I contrast responses to two types of events: days where the objective risks of attendance increase, and days where the *awareness* of such risks increases. The first type of event is straightforward to measure: I identify differential absences and withdrawals on days where local ICE enforcement peaks. For the second, I examine the roll out of a state immigration-enforcement law that received immediate push back in court – giving temporal variation in treatment. At points, the law appeared to move forward, with updates showing large setbacks to the civil suits against it. Here, the objective risk to deportation has not changed – the law was paused by federal judges. But, these negative updates increased the *salience* of the risks already there, reminding families of the risks they incur. Lastly, to look at the combination of increased salience and risk, I examine the time period when portions of the law actually clear federal court, which not

³An exception would be a student who is a legal permanent resident, but commits a felony

⁴ [Charlotte-Mecklenburg Schools seek protection from immigrant arrests](#)

⁵ At the same time, enforcement is consistent throughout the 10 years of daily ICE apprehension records used in this study, with an arrest of some type of arrest in the community occurring 47% of school days sampled.

only received ubiquitous news coverage but also increased explicit risk for undocumented individuals by expanding the scope and authority of local enforcement.

I find strong differential attendance choices of undocumented Hispanic *and* documented Hispanic students, relative to non-Hispanic white students, on days following a setback to the civil suit against the immigration-enforcement law. When such updates emerge, undocumented Hispanic students are 14% to 24% percentage points more likely to be stay home from school, accounting for the highest rate of absenteeism during the entire school year. However, when portions of the law are upheld in federal courts, undocumented students withdraw from school in increased numbers within the week.

Alternatively, there is no change in attendance behavior on days that immediately follow increased ICE enforcement. Using a panel of apprehension records obtained through a FOIA request, I am able to match arrests that occurred within the same area as schools, with special attention given to the arrest methods that would be most consequential to the community. There is little evidence of differential attendance behavior after dates where local, state, and regional ICE enforcement peaks.

To reconcile the distinct findings of reactions to legislative events and not to ICE enforcement, I use daily, locally-matched Google Trends and weekly local Spanish-language newspaper archives to proxy for community perceptions. During the legislative events, the coverage of the law is omnipresent in each. The results are most stark within the search behavior in the community, with Google searches for *ley* ("law") spiking the legislative roll out time period. Conversely, peak ICE enforcement events do not translate to strong Google Search trend behavior.

Looking across these findings, statutory changes that loosen constraints on local enforcement appear to have salience, whereas students are unresponsive to spikes in actual enforcement numbers. While daily ICE enforcement presents a real risk to school attendance, it is unpredictable. Individuals cannot form predictive strategies, and attend school regardless, even on dates following high enforcement totals. Conversely, a negative update on the legal case does not change the actual risk of going to school, since nothing has been decided in court. But, such negative updates increase the salience of risk. These are the days where undocumented students are substantially more likely to be absent. However, when

the law clears federal court, both dimensions move: the actual risk of enforcement increases *and* the salience of such risk increases. At this juncture, estimates suggest some families choose to withdraw from school and move elsewhere.

Relevant Literature

This study increases our knowledge of early investments in human capital as well as immigration. When thinking about optimal human capital investments and outcomes, early investments matter for short (Krueger and Whitmore, 2001) and long term outcomes (Chetty et al., 2011). Also, attendance is a crucial input to this human capital investment cycle (Goodman, 2014; Gottfried, 2009). Additionally, attendance is a granular, small investment that reflects the inherent costs and benefits to schooling, and it could also be a rough first proxy for effort. But how do stress and risk affect those investments? Given the changes in risks and risk salience for this population,⁶ I can examine the particular combinations that affect a student’s attendance choice. This contrasts to other empirical research where the measured interaction between a student’s choice and the amount of risk they face is fuzzier.

This research also adds to the literature on immigration, and specifically the education of immigrants. Much of the research on immigration has examined its perceived effects on labor markets (Card and DiNardo, 2000; Borjas, 2003; Hanson and Spilimbergo, 1999; Winegarden and Khor, 1991), resource allocation (Borjas and Hilton, 1996) or externalities (Diette and Uwaifo-Oyelere, 2014; Baker, 2015; Conger and Turner, 2015). Typically this research has been confined to looking at legal immigrants due to data constraints. Thus, our knowledge on undocumented individuals and their behaviors and interactions with institutions has been limited.

A large concern within immigration policy is evaluating the behaviors of immigrant populations and the possibility of negative externalities on native populations (crime,

⁶Some of these laws require local law enforcement to assert the documentation status of an individual during any stop or arrest. In 2007 and 2010, Arizona was the notable first mover on this policy. The state for this analysis not only enforced this “stop and identify policy” but also began barring undocumented immigrants from attending public post-secondary institutions, being transported by native citizens, renting property, and applying for jobs. A large increase in detentions and apprehensions by ICE occurred after this law (TRAC, Syracuse)

educational outcomes, resource competition, etc). Within education and immigration, knowing how immigrant students in the classroom affect native students is crucial to policy. Immigrant students seem to do better academically than native-born students of similar ethnicities (Stiefel et al., 2010). Additionally, there are generational tiers to academic performance for immigrants, with first generation immigrants outperforming second generation immigrants and third generation immigrant students doing no better or worse than their native cohorts (Özek and Figlio, 2016). Evaluating externalities in the classroom is difficult given the lack of information on a student’s immigration status. Diette and Uwaifo-Oyelere (2014) proxy for this using English as a Second Language (ESL) status and find some evidence confined to peer-effects on white and black males in North Carolina, whereas Conger (2015) finds no such externalities in the classroom among foreign-born peers.

Another research vein evaluates reactions to the Deferred Action for Childhood Arrivals (DACA), a major policy shift for undocumented individuals. DACA extended deportation protection and work eligibility to individuals meeting a narrow set of criteria. This seemed to have a cascade effect on many outcomes such as teen pregnancy, graduation, college attendance, poverty reduction and labor market entry (Kuka et al., 2018; Amuedo-Dorantes and Antman, 2016; Pope, 2016). Additionally, DACA students are highly sensitive to tuition increases/decreases, while not crowding out financial aide services for natives (Amuedo-Dorantes and Sparber, 2014; Conger and Turner, 2015).

Lastly, a new thread of research has developed around the roll out of two Immigration and Customs Enforcement (ICE) programs- “287(g) agreements” and “Secure Communities.” Each of these programs expanded the local enforcement abilities of ICE mainly via information sharing. Since these programs were implemented county-by-county over time, researchers can exploit this quasi-experimental variation, to establish causal estimates of population effects. As these ICE programs roll out, there are large decreases in Hispanic enrollment in K-12 schools (Dee and Murphy, 2018), decreases in Hispanic student test scores (Bellows, 2018), and decreases in SNAP and SSI enrollment (Alsan and Yang, 2018).

Overall, these aggregate effects have yet to be examined at the individual level, due to the lack of individualized documentation records. Thus, several identification strategies have surfaced to clarify this murky topic. Typically this distills to two strategies 1) using survey

level data to extrapolate samples onto the wider population and 2) proxy for immigration via a language-learning exceptionality. In fact, [Kuka et al. \(2018\)](#) state “there are no available data over this period that contains information on legal status and education for a large sample of youth” and clarifies that research must turn to second-best identification strategy of using ACS data to extrapolate undocumented populations upon aggregate data ([Pope, 2016](#); [Kuka et al., 2018](#); [Dávila and Mora, 2016](#); [Amuedo-Dorantes and Antman, 2016](#)). In the research that follows, my ability to accurately ascertain a student’s documentation status allows me to ask new questions, such as the differentiated response of documented and undocumented Hispanic individuals to enforcement. One finding is that both undocumented and documented students are responsive to an immigration law’s movements, evidence that the risks from immigration enforcement are borne by children regardless of their immigration status.

Background and Data

Education records used in this paper come from a mid-size school district covering the years 2004-2018. *Plyler v. Doe (1982)* established that students cannot be refused or charged for public education services based on documentation status; thus, undocumented students can and do enroll in public schools. Typically, these students cannot be differentiated from their peers of similar demographics. However in the data used here, children lacking documentation can be identified at the individual level.⁷ Combined with ethnicity, this individual indicator allows me to distinguish Hispanic students lacking documentation from those having documentation. Thus, I can observe the daily differential attendance choices of these two subpopulations. A rich set of controls is available, including grade level, age, Free/Reduced Lunch status, special education status, school demographics, yearly achievement data (standardized test scores), quarterly grade book records, daily attendance, and disciplinary data.

⁷Per my Institutional Review Board, further details on the creation of this flag have been omitted, given the inherent sensitivity of the data. For robustness in accuracy, please see Table 2.3 comparing the combined US-Entry, Limited English Proficiency, and undocumented tabulations across white and Hispanic students. Also, Figure 2.2 shows a graphical comparison of undocumented across subgroups.

The timing of this education panel overlaps the timing of the host state’s roll out of an immigration-enforcement law. This law mirrored the popular Arizona SB 1070 statute (a common theme for many states in the 2010s), which expanded the local enforcement capacity of state and local governments by requiring local law enforcement to verify documentation status of individuals appearing to be undocumented (“stop and identify”), penalizing those harboring or hiring undocumented individuals, and barring local governments from ignoring federal immigration statutes. In general, these laws expanded the immigration enforcement ability of states, which increased the objective risk of deportation for undocumented individuals.

Upon passage, the law faced several civil suits on the basis of constitutionality. At times, it was provisionally blocked, and at other times, it moved forward with some provisions being struck down, and others put into place. At all times, the case received widespread news coverage, especially in the Spanish-speaking media. These different episodes allow me to contrast the choices of students when the law 1) appears that it is trending towards passage, and 2) actually clears federal courts. The first type of event reflects the important of risk salience – the law has not cleared court, thus the actual risks for undocumented students have not changed. The actual clearance of the law moves both dimensions – the salience of risks and actual risks.

Enforcement Data Quantifying the risks populations face can be difficult. For undocumented students, the risk of deportation is best encapsulated by measuring immigration enforcement arrests conducted by ICE, rather than deportation data itself, since deportations represent the last link in a lengthy chain of administrative events (arrests, court dates, transfers to other facilities, final orders, etc). ICE apprehensions, on the other hand, represent the first link in that administrative chain and a high number of such arrests within a day usually constitute the colloquial “ICE raid.”⁸

I combine two unique enforcement data sets to capture as many factors as possible. The first comes from a partnership with the Transactional Records Access Clearinghouse

⁸I avoid using the term “ICE raid” here, since there is no explicit definition on how many arrests (criminal or non-criminal) must occur in one day to constitute a “raid.”

(TRAC),⁹ which compiles a large warehouse of data on ICE enforcement statistics. This gives a panel of daily arrests at the national, state, and county levels. Yet, using aggregate ICE enforcement levels might incorporate problematic noise. Specifically, ICE apprehends individuals for a multitude of violations, some of which might not influence an undocumented individual's risk profile. For instance, Criminal Alien Program (CAP) apprehensions typically are logged by ICE when individuals are transferred from local or state custody to ICE custody. For an undocumented family, this type of jail transfer is unlikely to represent an increased objective risk of deportation or the salience of such. Additionally, aggregate arrests could include criminal arrests that were transferred to ICE, jailed individuals being requested for transition to ICE custody, or other administrative apprehensions (all of which might not affect the behavior of an undocumented individual).

To specify the more relevant ICE enforcement events, TRAC uniquely coded some individual apprehensions as community arrests, where the “individual was located living in the community and arrested directly by ICE” (TRAC). These type of arrests would likely be the most influential to students and their families, as these arrests are targeted for deportation directly. These data are limited to October 2014 through May 2018, which gives an analytic sample of 4 academic years (2015-2018).

The other data source for enforcement risk comes from a Freedom of Information Act request I filed with ICE. These data include individual-level arrest statistics, which means concrete daily arrest totals can be calculated at the local level (geographically at the jail-location level). I then match these daily total arrest records to the area surrounding the school district. With this FOIA-obtained data, the aforementioned community-arrest specification is unavailable, but a longer analytic sample (2008-2018) affords an observation of pre-DACA and pre-Secure Community trends in the data. Like the TRAC records, I am able to bracket different types of enforcement. Again, any undocumented individual arrested for criminal activities (drunk driving, theft, etc.) might not preempt community concern, and therein differential absence behavior. To eliminate such criminal arrests, I use an administrative arrest code, “Located Arrest,” per ICE's definition. These Located Arrests are targeted community apprehensions for immigration violations, but in a more

⁹TRAC: <http://trac.syr.edu/phptools/immigration/arrest/>

narrowly defined format by ICE. This is opposed to the TRAC “Community Arrest,” which can include multiple layers of ICE enforcement. Again, if multiple individuals are arrested for non-criminal behavior (i.e. immigration violations only) this should have a larger effect on these communities, especially if multiple individuals are arrested.

Combining the TRAC and FOIA-obtained ICE records creates a granular picture of enforcement levels, and totals on any given day in this study area. Additionally, this allows an examination of any changes in enforcement during the roll out of the state immigration-enforcement law. In Figure 2.1, I display these daily data for the geographic area matching the school district, comparing both types of local arrests – Community (TRAC) and Located (FOIA) – to the CAP arrest totals from the FOIA data. First, the general ebb-and-flow of ICE CAP enforcement activities with peaks in the early 2010’s and again in recent years matches administrative policies. Second, local arrests in the community are consistent in recent years, but also include days of large spikes enforcement. Lastly, the data between the TRAC estimates and FOIA estimates seem to match one another, which gives confidence in the data’s consistency. Hereon, I refer to TRAC “Community Arrests” and ICE “Located Arrests” as simply “arrests,” although the empirical specifications control for these measures separately.

Legal Data The last type of risk that I quantify follows the progression of the state immigration enforcement law. Again, specific details are omitted for the sake of preserving the anonymity of the district. But it should be intuitive that any changes to local and state laws can be interpreted across the two previously mentioned margins. First, legislative risk pushes the objective risk of deportation up by providing the executive branches of the state to increase the level and thoroughness of enforcement. An individual could easily interpret that enforcement is unleashed after such a law is signed, upheld, or ratified. Secondly, legislative risk pushes the subjective risk of deportation up since the aforementioned objective risk is highly visible. To insure that these events were in fact salient, I collected a local Spanish-language newspaper’s archival records spanning 2006-2018, scanning the front page as well as the full text of an article if the topic was related to local immigration enforcement.¹⁰

¹⁰ I made these articles locally searchable by using Google Drive’s OCR services for better reliability. The newspaper’s general coverage of events seems to mirror the enforcement graphics above – strong coverage

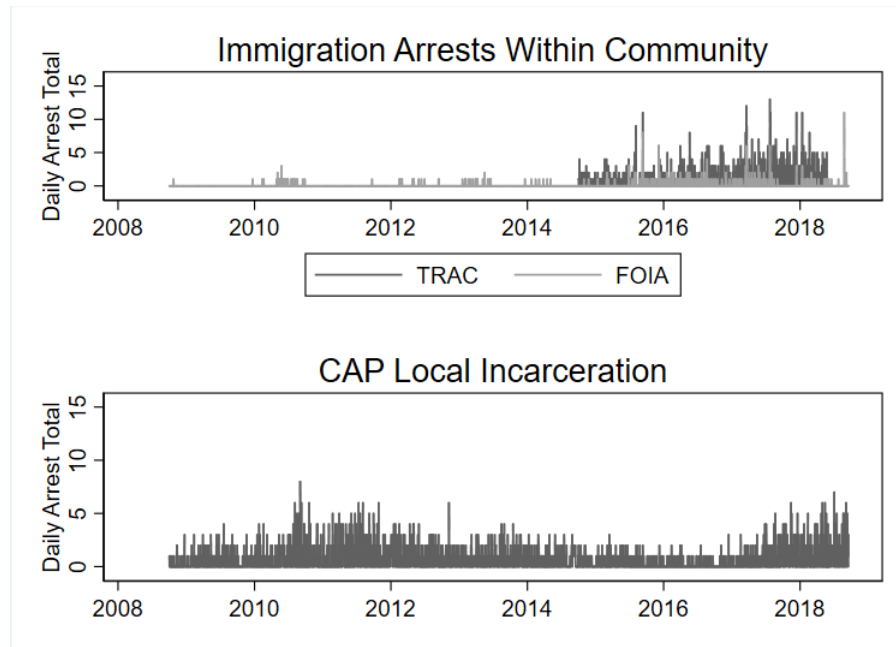


Figure 2.1: Local Area ICE Enforcement: Apprehensions in the Community TRAC-sourced and ICE-sourced (top panel) vs. Criminal Alien Program(CAP) Arrests (bottom panel)

Note: "TRAC" arrests reflect the daily number of individuals apprehended by ICE in the local area, as coded by TRAC. "FOIA" arrests reflect daily number apprehended by ICE, as coded by ICE from a FOIA request. These local arrests are different than Criminal Alien Program (CAP) arrests, which are apprehensions that can occur when a suspect is transferred from local custody to ICE custody, originating from non-immigration violations.

During the legislation’s roll-out, front page articles are dominated by the various nuances of the case – from setbacks to the civil suits, to background on the key judges involved.

Descriptive Data I matched daily attendance and student records to the dates of ICE enforcement and legal data listed above. Two important caveats to discuss are academic year 2011 and DACA eligibility. First, I drop academic year 2011 from this sample because of an unusually high rate of missing data on attendance. District officials credit a server issue that affected that year’s records only. Additionally, withdrawal data prior to 2011 is imprecise, so I only use withdrawal records from academic year 2012 and onward. Secondly, the Deferred Action for Childhood Arrivals (DACA) program is an important indicator variable to include, as this might alter a child’s perceived risks. Enacted in June 2012, DACA provided a two-year authorization to work and protection from deportation for young immigrants brought to the United States as children. This applied to children without lawful status who a) were under the age of 31 as of 2012 and physically present in the U.S. b) entered the United States before reaching the age of 16, c) have continuously lived in the US since 2007 without conviction of a felony or significant misdemeanor, d) were currently in school, graduated, possessing a GED or having the status of honorably discharged veteran.

While stipulating the lack of documentation was straightforward in this panel, DACA eligibility has to be inferred using the requirements of the program.¹¹ To do so, I took the pool of undocumented students and used their earliest record in the system, whether that be their formal US entry date, Limited English Proficiency (LEP) entry date, or earliest date in school. I then pooled the undocumented population into DACA-eligible and not-eligible based on the earliest record being before June 2012, and their birthdate less their earliest record being less than 16 years (to satisfy the DACA age requirement). The other DACA requirements (age less than 31, no documentation status, and enrolled in school) hold for all enrolled undocumented students in the panel.

The descriptive statistics in Table 2.2 and 2.3 show the ethnic and racial makeup of individuals in the education panel, inclusive of the documentation indicator and DACA

pre-2014, a few years of little activity, and then resumed coverage in the most recent years. This gives me confidence that these different data reflect the same events in the community, albeit through different lens.

¹¹complicated by the inconsistent administrative records of an individual’s first arrival in US

eligibility. For the analytic sample at the system level, the majority of students are Black or White, with 7.6% of students being Hispanic. Of those Hispanic students, 18% are undocumented.¹² Within the undocumented population of Hispanic students, more than 26.5% would be eligible for DACA. Additionally, the economic status for these students can be proxied by their Free/Reduced lunch status. Students are eligible for Free/Reduced lunch when their parents or legal guardians earn under a certain income threshold – indexed by the number of children in the household. To avoid inconsistencies, I collapse this to a binary indicator of whether a child has *ever* been on Free/Reduced lunch.¹³ At the system level, 69.6% of students have been on Free/Reduced Lunch at some point in the analytic sample. For Hispanic students, in general and for undocumented Hispanic students, 91.8% are on Free/Reduced Lunch. Compared to the mean of NCES school data, this district is relatively poorer, with a smaller Hispanic population and a larger black population.

An illuminating feature of these data is the ability to compare documentation to common proxies in research. For instance, within the Hispanic population over 84% of the population is marked as Limited English proficient. However, 18% are undocumented, which means this naive proxy of documentation severely overestimates the undocumented population. Conversely, any student who had a record of US-Entry makes up only 10.8% of this Hispanic population. This yields to a significant underestimate of the undocumented population.

Taking the unconditional means of the percent of sub-populations absent in Table 2.1, undocumented students appear to be absent more often than their documented Hispanic peers. Yet at this aggregate level, both groups of Hispanic students are absent less frequently than white students.

Figure 2.3 contains the density of absences for each subgroup. For Hispanic students (undocumented and documented), there is similar yearly absence totals, with documented students being represented more in the far right tails. Comparing undocumented Hispanic students to white students, undocumented students have fewer yearly absences than white students.

¹²Please see Figure 2.2 for comparison by years

¹³This categorization is dropped in the empirical framework, and the time-varying lunch status is used.

Table 2.1: Daily Mean Percent of Sub-Population Absent

	Mean	SD
Hispanic: Undocumented	0.047	0.026
Hispanic: Documented	0.037	0.020
All Hispanic	0.039	0.020
Black	0.041	0.022
White	0.052	0.023

Note: Mean and standard deviation are for the unique number of students absent each day divided by the population size of each subgroup.

Table 2.2: Individual Descriptive Statistics: District-Wide

	District Mean	National (NCES)* Mean
Male	0.513	-
Black	0.486	0.155
White	0.424	0.495
Hispanic	0.076	0.254
Free-Reduced Lunch	0.696	0.520

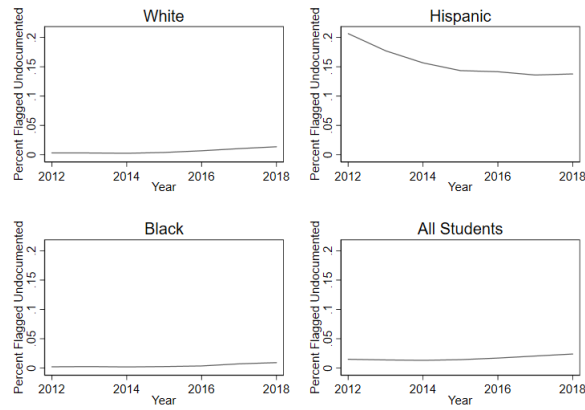
*Taken from the NCES 2013-2014 Report

Means taken for each unique student group. Free-Reduced Lunch status collapsed to students who have ever qualified for the program.

Table 2.3: Individual Descriptive Statistics

	Hispanic	Hispanic- Undoc	Asian	White	Black
	Mean	Mean	Mean	Mean	Mean
Male	0.512	0.533	0.512	0.513	0.512
Free-Reduced Lunch	0.918	0.912	0.423	0.495	0.840
Limited English Proficiency	0.848	0.932	0.535	0.005	0.004
Undocumented	0.180	1.000	0.126	0.010	0.007
Record of US Entry	0.108	0.509	0.189	0.002	0.001
DACA-Eligible	0.048	0.265	0.006	0.000	0.000

Means taken for each unique student group. DACA-Eligible reflects Hispanic students who would be eligible for DACA. Take up of DACA is not coded in this panel.

**Figure 2.2:** Percent of Sub-Population Undocumented

Note: Note: Each line shows the percent of each subpopulation flagged as undocumented over the panel. On aggregate, more documented-Hispanic students are entering the system, rather than an exit of undocumented students.

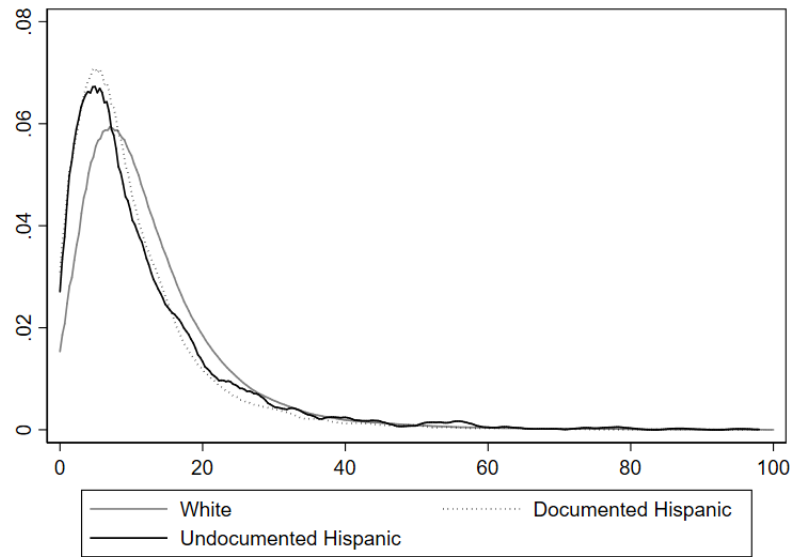


Figure 2.3: K-Density of Yearly Absence Totals for White, Hispanic-Documented and Hispanic-Undocumented Students

Note: Kernel density estimated using Epanechnikov kernel function for yearly total absences for each students, grouped by subpopulation. Students amassing more that 100 absences are not included in this figure.

Empirical Framework

The novelty of this setting is the ability to uniquely identify the lack of documentation on an individual basis, combined with granular attendance data matched to both sources of ICE apprehension data and the timeline of important movements in the area’s immigration law. With this clarity in documentation, I can chart the reaction to the immigration-enforcement law in unconditional graphics. In Figure 2.4, the percent absent from each subgroup is plotted against the dates spanning the roll out of the immigration-enforcement law. The two “negative” updates (where a report casts doubt upon the law being permanently blocked) are plotted as dotted vertical bars and the law’s clearance of federal court as a dashed vertical bar. Undocumented *and* documented students are absent in high proportions on the days where these negative updates occur. When the law clears federal court, a noticeable, but less dramatic uptick in absences occurs in the undocumented student population.

Secondly, the subpopulation that withdraws from school is plotted over the same time period (Figure 2.5). This is collapsed to the weekly-level, given that administrative entry or logging of withdrawals may be delayed by a few days. White students show no higher propensity to withdraw over this time frame, whereas 3% of the undocumented population and 1% of the documented population withdraws within a week of the immigration-enforcement law moving forward in court. A portion of the documented student population withdraws too, but of a considerably lower magnitude as undocumented students. The withdrawals of undocumented students represents a significant shift in withdrawal behavior as seen in the cumulative withdrawals plotted in Figure 2.6. While the undocumented population is a highly mobile group, the immigration-enforcement law appears to induce earlier withdrawals that respective year.

Since it is possible that these key dates in the panel could be conflated with holidays or days with higher absences (e.g. Friday), I next turn to a conditional model. To estimate the magnitude of undocumented and documented students’ absence and withdrawal anomalies conditional on additional student features (free lunch status, gender, etc.), I estimate the following model of individual i ’s absence or withdrawal on day t within month m and day of the week d :

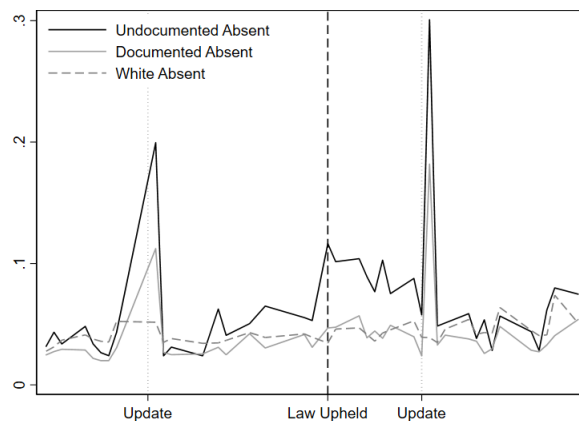


Figure 2.4: Percent Sub-Population Absent, Immigration Law Roll Out

Note: Each line is the daily absence rate for the respective subpopulation (number of students absent/total number of enrolled students on that day). The two updates occur when legal proceedings appear to cast doubt on the immigration enforcement law being permanently blocked. The Law Upheld time line occurs when key provisions of the immigration-enforcement law are cleared to move forward.

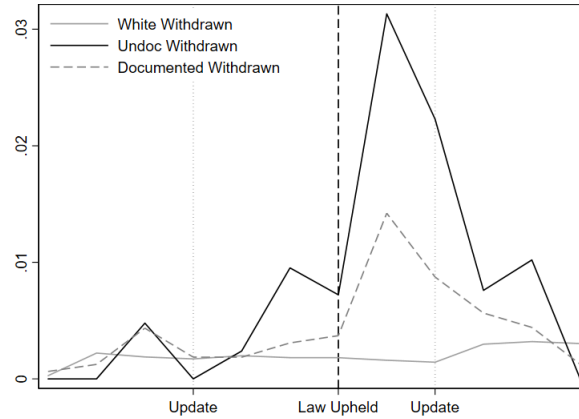


Figure 2.5: Percent Sub-Population Withdrawn Within 5 School-Day Period during Immigration Law Roll Out

Note: Each line is the 5-day withdrawal rate for the respective subpopulation (number of students withdrawn/total number of enrolled students within that week). The two updates occur when legal proceedings appear to cast doubt on the immigration enforcement law being permanently blocked. The Law Upheld time line occurs when key provisions of the immigration-enforcement law are cleared to move forward.

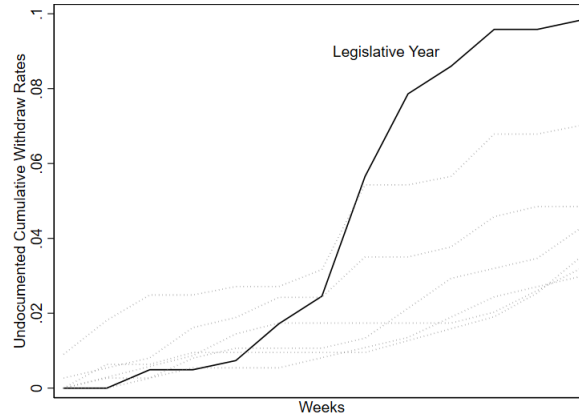


Figure 2.6: Cumulative Percent Sub-Population Withdrawn During Term of Immigration Law Roll Out

Note: Each line is each respective academic year's 5-day cumulative withdrawal rate for the respective subpopulation (number of students withdrawn in current period in addition to all previous periods /total number of enrolled students within that week).

$$Y_{itmd} = a_0 + \beta_{U_1} KEYDATE_t * UNDOC_i + \beta_{D_1} KEYDATE_t * DOC_i \\ + X_{it}\Phi + \Theta_m * \overrightarrow{subpopulation_i} + \Theta_d * \overrightarrow{subpopulation_i} + \Theta_t + \epsilon_{it} \quad (2.1)$$

Y_{itmd} is the outcome of interest, specified here as the binary outcome of being absent on the date following the event or, in the case of withdrawals, withdrawing from the system within five school days. $\hat{\beta}_U$ and $\hat{\beta}_D$ are the estimators of interest, capturing the interaction between documentation status (undocumented Hispanic, and documented Hispanic, respectively) and the $KEYDATE_t$ indicator vector (i.e. the date of an update or the law being upheld). $\hat{\beta}_U$ and $\hat{\beta}_D$ are estimated from the panel for academic years 2012-2018 given the withdrawal imprecision referenced earlier. $\hat{\beta}_U$ and $\hat{\beta}_D$ are conditional differences in Y_{itmd} for undocumented and documented students relative to white students, who serve as for a control group to help eliminate unobserved factors contributing to shared, district-wide absence or withdrawal behavior.¹⁴ Free and Reduced Price Lunch status is the best proxy for economic status in the panel, and grade level is an important control, given differential schooling behaviors. Θ_t specifies a fixed effect for the date, Θ_m month-by-subpopulation indicator fixed effects (i.e. month-by-white, undocumented Hispanic, or documented Hispanic fixed effect) and Θ_d a day of the week (Monday, Tuesday, etc) by subpopulation fixed effect.

This flexible estimation allows me to specify the differential effect of days where legislation changes or immigration enforcement peaks. To include these events in a condensed format, I estimate (within the same equation) point estimates for each of the major updates to the immigration-enforcement law and the law being upheld in court. For ICE enforcement data (both TRAC and FOIA derived), I take the dates of the top 10% highest arrest counts as a

¹⁴While it would be instructive to compare the Hispanic students to black students in the panel, there is evidence that these two populations may share similar reactions to ICE enforcement [Bellows \(2018\)](#) and therein immigration concerns in general, making for an inappropriate reference group.

Table 2.4: Regression Results of All Events: Absence and Withdrawal Likelihood

<i>Legislative Updates</i>	Absence	Withdrawal
Update 1 x Undocumented Status	0.149*** (91.68)	-0.000196 (-0.37)
Update 1 x Documented Status	0.0713*** (88.75)	-0.000113 (-0.46)
Upheld x Undocumented Status	0.0138*** (8.46)	0.00565** (2.71)
Upheld x Documented Status	0.00415*** (5.17)	0.00253** (2.82)
Update 2 x Undocumented Status	0.263*** (176.20)	0.00246 (1.40)
Update 2 x Documented Status	0.157*** (182.79)	0.000666* (1.96)
<i>Dates of Enforcement</i>		
Top FOIA-ICE Dates x Undocumented Status	-0.00722 (-1.55)	-0.0000597 (-0.42)
Top FOIA-ICE Dates x Documented Status	-0.000446 (-0.09)	0.0000162 (0.22)
Top TRAC-ICE Dates x Undocumented Status	0.00945** (3.11)	-0.000300* (-2.43)
Top TRAC-ICE Dates x Documented Status	-0.00266 (-1.35)	0.0000483 (0.51)
<i>Alternate Dates of Importance</i>		
Holiday x Undocumented Status	-0.0161*** (-10.70)	0.000322 (0.28)
Holiday x Documented Status	-0.0506*** (-34.56)	0.000830*** (4.10)
Observations	~ 24600000	~ 24600000

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Each absence estimate is the interaction between documentation type and respective date indicator. ¹⁵

combined indicator for “Located Arrests” within the FOIA data, and “Community Arrests” dates from the TRAC data.

Consistent with the unconditional figures, Table 2.4 shows undocumented students have a high propensity for absences following the two updates to the immigration-enforcement court case. Specifically, undocumented students are nearly 14.9% and 26.3% more likely to miss school on days where announcements from court cast doubts on the stoppage of immigration-enforcement case. Additionally, documented students respond similarly though at not as high of a magnitude. Withdrawal rates are unchanged during these two updates. When the immigration-enforcement law clears court, there is significant withdrawal behavior and absence behavior among undocumented children. Again, documented students seem to have similar behaviors at a smaller scale.

For context, I look to estimated effects of days that preceded major holidays (where a high proportion of students are absent, regardless of ethnicity) and the “Day Without Immigrants” protest (a 2017 nationwide event). This places the estimated effect far outside days preceding holidays and yet near to a major nationwide protest.

For ICE enforcement dates, an inconsistent pattern emerges. Most dates are insignificant, with TRAC peak dates showing a precise estimate. Yet, they are orders of magnitude less than the corresponding estimates of holidays and A Day Without Immigrants. For perspective on these estimates, I describe a placebo model in a following section. Specifically, the significant estimates for TRAC ICE dates are squarely within the estimates of dates picked at random, as visualized in Figure 2.9.

Salience and Google Trends

The contrast between the high level of absences after legal changes and not after ICE enforcement events presents a confusing juxtaposition of results. Both both of types of events are highly consequential to undocumented Hispanic students, yet only one type leads to large responses. However, a major reason for differential responses could be the salience these events. Getting an empirical assessment of the events that are most salient via surveys (especially for this sensitive population) would be difficult. But, if community members

are turning to online media sources for information, I can observe keyword search behaviors from Google Trends. Specifically, I can compare the search behavior around ICE enforcement events versus legislative events.

Google aggregates, stores, and makes publicly available daily search data, at the city/county level depending on search volume. I chose to use a combination of formal and vernacular words since the search engine cannot distinguish between searches for “ICE” (Immigration and Customs Enforcement) and “ice” (frozen rain, ice cream, or icy road conditions).¹⁶ For vernacular terms, I chose two terms (“la migra” and “migra”) that are harsh shorthand for “inmigracion.” For more formal searches, I use “ICE raid” “I . C . E .” and “ICE raids” to perhaps evaluate ex-post enforcement that landed in the local news cycle, but not the national scope.¹⁷

To fold Google Trends into the education records spanning 10 years, I calculate a relative score for each search term. This is required since Google reports a 0-to-100 daily search score, not the aggregate volume of searches. Additionally, Google Trends *daily* data can only be pulled in 90-day increments. Thus to temper those pulls, I use Google’s monthly data, which covers the entire time span (2006-2018) to construct the relative importance of a month. I convert this monthly score to a rate and then multiply it against each date’s Google Search trends, to yield a relative, time-correct score.

I plot Google Search behavior around the period where legislation is moving through the courts and Google Search trend behavior around ICE enforcement in Figure 2.7. Since the FOIA-obtained data cover the entire panel, I use ICE arrests as the backdrop for comparison. In the first panel, there is a striking peak of searches for “ley” (law) during the time of the legislative roll out, but not around ICE enforcement. In the second panel, the four terms listed above (“la migra,” “migra,” “I.C.E.,” and “ICE raids”) are plotted against the same Located Arrest data. Here, if there was a strong salience to ICE enforcement events, there should be Google Trend peaks around the largest enforcement events. Instead, there does not seem to be a pattern between proxied perception and actual enforcement levels. Overall,

¹⁶Search trends for ICE correlate with searches for “snow” and the “Ice Bucket Challenge” which further bolsters the decision to drop ICE as a standalone term.

¹⁷Confoundingly, these search terms are clustered tightly around the “Day Without Immigrants” protest, where there were high concerns and interest that enforcement might use this as an opportunity for arrests (I see a larger number of individuals arrested on that day too)

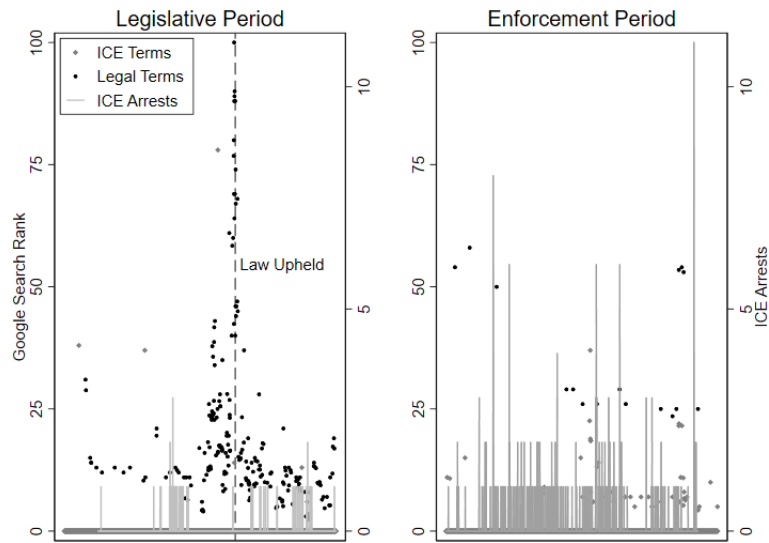


Figure 2.7: Daily Google Search Trends

Note: Daily Google Search trends are indexed for their monthly relevance, giving a relative daily score $0 \rightarrow 100$. “Migra” is a harsh slang term for immigration enforcement. “Ley” is Spanish for law.

it seems clear that legislative movements were highly salient to the local Spanish-speaking population, whereas ICE enforcement does not seem to be reflected in search trends.

Placebo Inference and Robustness

As mentioned in the discussion of Table 2.4 results, the model’s estimates should be compared to other dates in the panel, especially given the high number of observations. Many of the main coefficients in Table 2.4 are very precise, yet small in magnitude. This makes it difficult to deduce how exceptional these dates are relative to other dates in the panel. To examine the relative magnitude of the legislative dates, I estimate the same model as before, except substituting a placebo date in for $KEYDATE_t$. I focus entirely on undocumented student absences, given the not only the granularity of this variable, but also the focus of this study. For thoroughness, I allow every date in the panel to serve as $KEYDATE_t$. Figure 2.8 contains a histogram of all estimated coefficients for the entire panel for absences, marking the estimates corresponding to legislative events. These estimates are well into the right tail of the distribution, with the first legal update outranking 99.8% all other dates, and the second legal update outranking 100 % dates. The coefficient of the law being upheld is larger than 67.6 % of all dates combined.

Comparatively, I also examine the relative importance of the estimates obtained from analyzing the dates of top ICE enforcement, against a batch of placebo dates. Since I have regressed a group of dates where ICE enforcement peaks upon student attendance, I create a placebo group of dates here by selecting the 10% highest values of a random number generator, associated to dates in the panel. This group of dates is then interacted in the same model as before, for undocumented student absences. I then iterate this design 1,000 times. Here, the estimates associated with true the ICE dates (specifically ICE-TRAC) are within the bulk of the coefficient estimates, with 9.3% of placebo coefficient estimates exceeding the ICE-TRAC absence estimate from Table 2.4.

Synthesizing these two brackets of placebo results – large coefficients on legal dates comparative to all other dates in the panel, versus small coefficients on the bundle of highest ICE enforcement – bolsters the main results of undocumented students’ absences are most

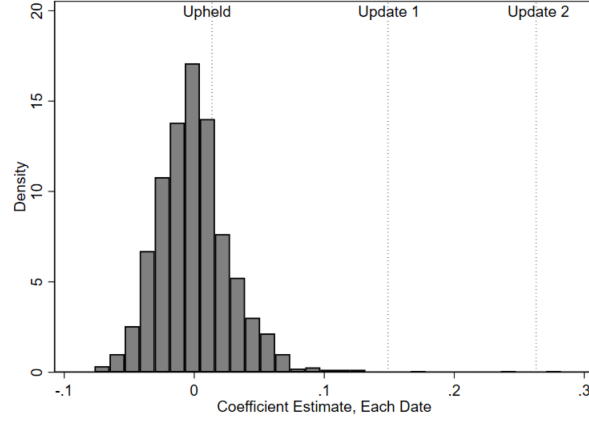


Figure 2.8: Placebo Dates as Inference- All Dates

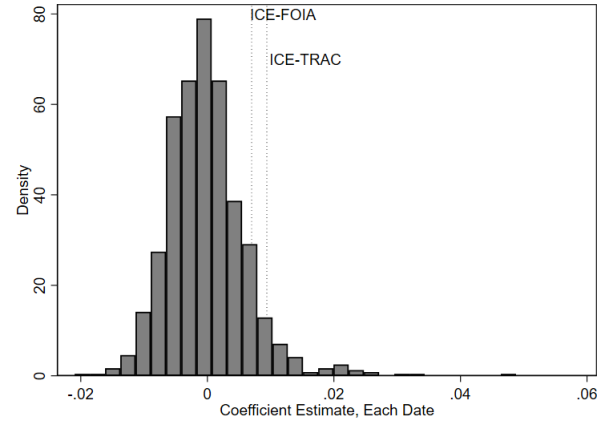


Figure 2.9: Placebo Dates as Inference- ICE Enforcement Comparison

Figure 2.8 uses every date in panel as an interacted $KEYDATE_t$ for undocumented students. Coefficient estimates from dates corresponding to the legislative roll out are superimposed as horizontal lines.

Figure 2.9 uses a bundle of dates in panel as an interacted $KEYDATE_t$ for undocumented students. Coefficient estimates from dates corresponding to the point estimates from the ICE indicator.

responsive to legal updates, and generally unresponsive to the most prominent dates of ICE enforcement.

Heterogeneity Analysis

Since salience around these legal events seems to be the driver of student attendance patterns, an important caveat is examining how different sub-groups of students react. First, I split the sample by gender to see if there are differential reactions between male and female students. In Table 2.5, the estimates nearly mirror the interaction of undocumented and major legal dates upon absences. For withdrawals and dates around ICE activity, there seems to be some heterogeneity in response within genders. For the results around ICE activity in Table 2.4, the responses seem to be driven by females, but the estimate is still exceptionally smaller as compared to the legal days.

Next, I split the sample by grade levels, bracketed by typical transitions (i.e. grades 6-8 from middle school, etc). Here I do see differential reactions, with students in high school grades (9-12) being the most reactive to the legal events, regardless of documentation status (Table 2.7).¹⁸ One particular estimate, the Update 2 x Undocumented Status increases to 0.43, which reveals the strong heterogeneity in response across grades. The particular mechanism for this reaction is unclear – speculative consideration by district employees posits older students have the ability to chose transportation on their own, whereas younger students cannot. Conversely, this trend is reversed for withdrawal estimates – with the highest estimates coming from undocumented students in grades K-5 (Table 2.8).

Lastly, I break out a student's duration within the school system (one year or less in the system versus more than one year) to examine the possibility that students who are new to the area are more reactive these events (Table ??). The estimates here are mixed, with new undocumented students to the system having absences slightly less reactive to Update 1 and more reactive to Update 2 and the law being upheld. For withdrawal around the law's

¹⁸These differences are indeed statistically significant, when including a triple interaction for each subgroup upon documentation status upon date. For example, Update 1 x Undocumented x Grades(6-8).

Table 2.5: By Gender: Absence Likelihood

<i>Legislative Updates</i>	Absence	
	Female	Male
Update 1 x Undocumented Status	0.149*** (71.47)	0.150*** (84.18)
Update 1 x Documented Status	0.0829*** (85.55)	0.0604*** (70.64)
Upheld x Undocumented Status	0.0182*** (8.74)	0.00978*** (5.50)
Upheld x Documented Status	0.00243* (2.51)	0.00598*** (7.00)
Update 2 x Undocumented Status	0.213*** (101.91)	0.308*** (181.55)
Update 2 x Documented Status	0.168*** (167.64)	0.146*** (159.10)
<i>Dates of Enforcement</i>		
FOIA-ICE x Undocumented Status	-0.0146* (-2.48)	-0.000572 (-0.10)
FOIA-ICE x Documented Status	-0.000347 (-0.06)	-0.000532 (-0.12)
TRAC-ICE x Undocumented Status	0.0127** (3.09)	0.00617 (1.89)
TRAC-ICE x Documented Status	-0.00336 (-1.52)	-0.00196 (-1.04)
<i>Alternate Dates</i>		
Holiday x Undocumented Status	-0.0345*** (-17.48)	0.000717 (0.40)
Holiday x Documented Status	-0.0514*** (-32.23)	-0.0495*** (-33.46)
ADWOI Protest Date x Undocumented Status	0.235*** (102.56)	0.191*** (103.14)

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Each absence estimate is the interaction between documentation type (undocumented-Hispanic or Documented-Hispanic) and respective date indicator. Absence estimates are for the day following the respective event, while withdrawal estimates are for the 7-day span following the event.

Table 2.6: By Gender: Withdrawal Likelihood

<i>Legislative Updates</i>	Withdrawal	
	Female	Male
Update 1 x Undocumented Status	-0.00230*** (-3.61)	0.0155*** (20.81)
Update 1 x Documented Status	0.000412 (1.33)	0.00193*** (6.09)
Upheld x Undocumented Status	0.0258*** (16.82)	0.0273*** (23.39)
Upheld x Documented Status	0.0201*** (47.00)	0.00507*** (14.95)
Update 2 x Undocumented Status	0.00835*** (5.43)	-0.00475*** (-4.08)
Update 2 x Documented Status	0.00333*** (7.80)	0.00168*** (4.97)
<i>Dates of Enforcement</i>		
FOIA-ICE x Undocumented Status	0.0000272 (0.02)	-0.000120 (-0.13)
FOIA-ICE x Documented Status	-0.0000873 (-0.23)	-0.000272 (-0.59)
TRAC-ICE x Undocumented Status	-0.000595 (-0.62)	-0.00170 (-1.65)
TRAC-ICE x Documented Status	-0.000634 (-1.11)	0.000701 (1.02)
<i>Alternate Dates</i>		
Holiday x Undocumented Status	0.00291*** (4.42)	-0.00320*** (-3.93)
Holiday x Documented Status	0.00381*** (13.02)	0.00288*** (10.96)

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Each absence estimate is the interaction between documentation type (undocumented-Hispanic or Documented-Hispanic) and respective date indicator. Absence estimates are for the day following the respective event, while withdrawal estimates are for the 7-day span following the event.

Table 2.7: By Grade Level: Absence Likelihood

<i>Legislative Updates</i>	K-5	6-8	9-12
Update 1 x Undocumented	0.0966*** (52.84)	0.111*** (53.41)	0.222*** (83.95)
Update 1 x Documented	0.0733*** (83.15)	0.0421*** (32.42)	0.139*** (82.53)
Upheld x Undocumented	0.0286*** (15.67)	-0.0165*** (-7.98)	0.0289*** (10.90)
Upheld x Documented	0.00434*** (4.92)	0.00235 (1.81)	0.0227*** (13.53)
Update 2 x Undocumented	0.0973*** (55.60)	0.229*** (117.53)	0.430*** (164.80)
Update 2 x Documented	0.123*** (151.51)	0.173*** (133.99)	0.293*** (155.74)
<i>Dates of Enforcement</i>			
Top FOIA ICE x Undocumented	-0.00523 (-1.53)	-0.00475 (-0.53)	-0.00435 (-0.41)
Top FOIA ICE x Documented	0.00247 (0.85)	-0.00190 (-0.29)	-0.00771 (-0.68)
Top TRAC ICE x Undocumented	0.000396 (0.13)	0.00593 (1.83)	0.00587 (1.04)
Top TRAC ICE x Documented	0.00176 (1.36)	-0.00515** (-2.68)	-0.000797 (-0.14)
<i>Alternate Dates of Importance</i>			
Holiday x Undocumented	-0.0602*** (-33.93)	-0.0595*** (-24.35)	0.0284*** (11.09)
Holiday x Documented	-0.0265*** (-26.40)	-0.0543*** (-34.46)	0.0191*** (9.08)

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Each absence estimate is the interaction between documentation type (undocumented-Hispanic or Documented-Hispanic) and respective date indicator. Withdrawal estimates are for the 7-day span following the event.

Table 2.8: By Grade Level: Withdrawal Likelihood

<i>Legislative Updates</i>	K-5	6-8	9-12
Update 1 x Undocumented	0.00584*** (7.53)	0.00509*** (6.50)	0.00990*** (12.46)
Update 1 x Documented	0.00230*** (7.10)	-0.00110** (-3.16)	-0.00168*** (-3.84)
Upheld x Undocumented	0.0418*** (24.65)	0.0342*** (16.93)	0.00770*** (6.85)
Upheld x Documented	0.0182*** (48.24)	-0.00171*** (-4.27)	0.00572*** (10.13)
Update 2 x Undocumented	0.00105 (0.62)	0.00290 (1.43)	0.00109 (0.97)
Update 2 x Documented	-0.00118** (-3.14)	0.00481*** (11.99)	0.0137*** (24.24)
<i>Dates of Enforcement</i>			
Top FOIA ICE x Undocumented	0.000379 (0.24)	-0.00138 (-1.56)	0.000271 (0.23)
Top FOIA ICE x Documented	0.000258 (0.67)	-0.00125* (-2.52)	-0.0000632 (-0.10)
Top TRAC ICE x Undocumented	0.000493 (0.22)	-0.00321*** (-4.27)	-0.000902 (-0.88)
Top TRAC ICE x Documented	0.000129 (0.22)	0.000401 (0.44)	-0.000223 (-0.33)
<i>Alternate Dates of Importance</i>			
Holiday x Undocumented	-0.00306* (-2.54)	0.00648*** (7.74)	-0.00329*** (-4.78)
Holiday x Documented	0.00588*** (24.11)	-0.00136*** (-5.06)	-0.00120*** (-3.88)

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Each withdrawal estimate is the interaction between documentation type (undocumented-Hispanic or Documented-Hispanic) and respective date indicator.

clearance, the results are still mixed – new students are less likely to withdraw and students with more than a year’s tenure in the system are more likely to withdraw.

Discussion and Conclusions

In this study, I estimate the effects of ICE enforcement and immigration enforcement legislation upon undocumented students by using educational records where the lack of documentation can be inferred. On dates of peak ICE enforcement, undocumented and documented Hispanic students do not attend school differently than white students. However, on dates where an immigration-enforcement law appears to move forward, undocumented Hispanic students are 14-26% more likely to be absent. When this law actually clears federal court, undocumented students have an increased likelihood of withdrawing compared to other students. These results seem puzzling adjacent to one another – undocumented students show dramatic behavior in the face of changes to immigration enforcement law, but not to enforcement itself.

The link between these behaviors appears to be driven by salience. ICE enforcement is unpredictable and thus prevents students and their families from engaging in avoidance, leaving attendance behavior unchanged. However, immigration-enforcement legislation affects the salience of one's risks in school and thus drives differential attendance when a stringent law moves forward. To examine salience, I use Google Trends and local Spanish-speaking newspaper records to verify that the local Spanish-speaking population was highly aware of the law. On the other hand, Google Trends searches for terms related to ICE enforcement show no relation to actual ICE arrests.

This emphasis on risk salience is sharpened by the budget set that undocumented students face. Students cannot be perpetually absent since the district has both an early warning program and truancy court. The early warning program would notify parents if a student was on the borderline of truancy, whereas truancy court would put a great deal of attention on the family – a non-trivial risk for undocumented families. Additionally, such families may lack information on “working” the system when their child is absent, as other students might (to switch unexcused absences to excused absences). This would mean that students will be absent where risk appears to be highest. In the context of an immigration-enforcement law, those dates would be where the law appears to moving forward in court. Given that some community members feared retribution, increased enforcement levels, or increased

enforcement participation (through local partnerships), withdrawing from school might be a optimal choice for families.

These results also inform the asserted linkage between ICE events (outside the current study area) and Hispanic absenteeism especially after the nationally-covered Mississippi and Morristown enforcement sweeps ([Shoichet, 2018](#); [Silverman and Hanna, 2019](#)). In these instances, enforcement seemed to be the key driver of reactions where a large enforcement sweep occurred, and then large spike in absenteeism followed. Yet, this anecdote mistakes risk and for the salience of risk. Students were not absent the day of the event, when the objective risk of attendance was actually the highest. Instead, students were absent once there was sufficient information available – the day *following* the event. This seems to infer that the salience of such risks was altered when this highly publicized enforcement event occurred. And where media reports might infer that Hispanic absenteeism during these periods is driven primarily by undocumented students, the results of this study show that the effects of salience effects are not localized to undocumented Hispanic students alone. Documented Hispanic students (many of whom are American citizens) seem to be affected similarly with spikes in around the same time, but at a lesser magnitude than similar to undocumented Hispanic students. This change in attendance behavior may reflect more consequential effects (psychological burdens, fear, etc) and reveal externalities of such legislation on native populations.

Overall, this paper sheds light not only on the implications and consequences of immigration-enforcement legislation (or the mere possibility of it) but also increases our understanding of undocumented immigrants, and human capital investments under multiple forms of risk. This, compared to inconsistent and insignificant results of ICE enforcement, emphasizes the role risk salience plays in the education investments families make for their children.

Chapter 3

DACA On and Off: Asymmetric Responses to Risk Protections

Introduction

In Becker’s (1962, 1993) canonical model of human capital investment, an advanced education is treated as risky and illiquid, which can negatively ripple backwards to the education choices of children and their families. The same could be said of effort exerted toward a compulsory primary or secondary education for students who might not be able to even enter the formal labor market after graduation. This was the scenario faced by many undocumented immigrants in the United States prior to the 2012 implementation of the Deferred Action for Childhood Arrivals (DACA), and beginning again in 2017 after DACA was suspended. In this paper, we are the first to examine the effect of DACA protections – their introduction as well as their removal – on student achievement and non-cognitive engagement with school.

DACA protected some undocumented immigrants from deportation for a renewable two-year term, and allowed them to obtain work permits. DACA-eligible individuals were undocumented immigrants who arrived in the U.S. prior to June 12, 2012, and prior to their 16th birthday, and who were under age 31 as of June 12, 2012. Importantly for our questions, DACA protections hinged on being enrolled in school or having completed a high school diploma or General Education Development (GED) certificate. Prior work

has shown that Hispanic foreign-born populations (a large portion of whom are estimated to be undocumented) were responsive to the workforce components of DACA, increasing labor force participation and moving out of poverty in large numbers ([Amuedo-Dorantes and Antman, 2016, 2017](#); [Pope, 2016](#)).

The effects of DACA on educational attainment appear to be more nuanced, which is unsurprising given the policy’s ambiguous incentives around schooling. Younger, school-aged individuals should be motivated by DACA’s requirements that applicants must hold a high school diploma, or be at least seeking one. Using the nationally representative American Community Survey, [Kuka et al. \(2018\)](#) show that school attendance and high school graduation increased among non-citizen Hispanic youth between age 14 and 18 after 2012. When DACA was introduced in 2012, the opportunity to obtain a work permit was not matched with a proportionate incentive to enroll in college, tipping the balance toward work. Furthermore, DACA does not alleviate the costs of postsecondary education for undocumented immigrants, who remain ineligible for federal loans and financial aid, and who face out-of-state tuition in most states.¹ [Kuka et al. \(2018\)](#) estimate imprecisely positive effects of DACA on college enrollment among all age- and nativity-eligible individuals, whereas [Pope \(2016\)](#), [Amuedo-Dorantes and Antman \(2017\)](#), and [Kuka et al. \(2018\)](#) find negative postsecondary effects of varying precision and magnitude when the focus narrows to high school graduates. Looking across studies, mixed results for postsecondary enrollment seem to suggest that the composition of the population of undocumented high school graduates changed under DACA protections, growing to include more students who would not have completed high school in the absence of DACA, and who are less apt to enroll in college regardless of DACA.

Our innovations in the literature on DACA are threefold. Foremost, we examine the effect of DACA protections on students who are still in primary and secondary grades, assessing whether renewable protection from deportation as well as the promise of legal work following high school elicits more engagement with school (measured by attendance), fewer disruptions (measured by disciplinary records), and better performance in classes (measured by course

¹See [Amuedo-Dorantes and Sparber \(2014\)](#) and [Conger and Turner \(2015\)](#) for evidence that undocumented immigrants enroll in college at greater rates when states pass legislation extending in-state tuition.

grades). Second, we provide the first view of how students responded to the removal of those protections by President Trump in 2017. And third, we depart from much of the related research on undocumented immigrants before and after DACA by accurately identifying undocumented, DACA-eligible students rather than defining a class of non-native individuals who are very likely to be undocumented.

Our setting is a mid-sized U.S. school district, where we can observe rich administrative data on enrollment, age, race, ethnicity, attendance, behavior, and grades over the years 2004-2018. We join [Conger and Turner \(2015\)](#) and [Hsin and Ortega \(2018\)](#) in our ability to infer documentation status at the individual level, and ours is the first study we know of to do so for primary and secondary grades.

In order to examine the effect of DACA protections on school engagement and success, we use a difference-in-difference identification strategy that compares schooling outcomes for Hispanic, undocumented, DACA-eligible students to the outcomes of their Hispanic documented peers, other undocumented students without DACA eligibility, and the outcomes of white students. Our findings indicate that DACA-eligible students exhibited more absenteeism and more behavioral infractions during the 2012 - 2017 program years, and no evident reversal of those patterns afterwards. Specifically, during DACA's "on" period, eligible Hispanic students have a higher volume of monthly absences and a higher volume of citations for fighting, albeit no differential change in total behavioral infractions. Additionally, students appear to have a lower core-class GPA during DACA, and a higher GPA upon its suspension, although these estimates are imprecisely estimated.

Our findings are consistent with a couple channels by which DACA could have influenced student behavior and engagement with school. By alleviating the risk of deportation, DACA shifted the expected costs of engaging in risky behavior such as missing class or fighting. But DACA also incentivized persistence through high school, and students on the margin of dropping out in the absence of DACA may have had sliding grades and deteriorating behavior. We also present preliminary evidence of this, by abstracting the current panel to a longer time span, and estimate the effects DACA had on student withdrawal from school. In ongoing work, we are estimating the effect of DACA on students with lower academic

achievement and persistence – the population most likely influenced by the aforementioned channel.

These responses not only add a granular nuance to our understanding of DACA, but an increased understanding of human capital investments with varying degree of risk. Before the policy, students were at a general risk of deportation from immigration enforcement. This meant that the returns to education were under a consistent, stochastic form of risk, which hypothetically could lead to the same amount of education sought by students not under risk. During DACA though, the program allowed for low deportation risk and increased ability to enter the formal labor sector. This may have disincentived education investments, reflected in our early findings, as students looked to graduate and enter the formal labor market. After DACA was suspended, the effects are mixed (reflected in the inconsistencies by specification in our results) as some students responded to the risk shock by reverting to previous human capital investment strategies, and others a detachment with educational attainment.

Background and Data

DACA

DACA was introduced on June 15, 2012 as an executive action by President Obama, whose authority over the Department of Homeland Security (DHS) led to a formal change in prosecutorial discretion of illegal immigration. Concurrent with the president’s announcement, the Secretary of DHS issued a memorandum inviting some individuals who illegally immigrated to the United States as children (“Childhood Arrivals”) to apply for a two-year renewable period of relief from the threat of deportation (“Deferred Action”) so long as they met certain criteria.

To be eligible for DACA, individuals must have resided in the United States continuously for the five years prior to June 15, 2012, must have been younger than 16 when they arrived in the United States, and must have been younger than 31 on June 15, 2012. Eligibility was also conditioned on having no criminal record and having attained either a high school

diploma or GED. DACA criteria additionally entailed a direct incentive to enroll in school, but only for those who were seeking a high school diploma, a GED, or who were enrolled in adult literacy or career training programs. DACA eligibility was determined through a formal application process that included documentation and review of these criteria, as well as biometric screening.

The first benefit of DACA to successful applicants was temporary lawful residence in the U.S. In the words of the U.S. Citizenship and Immigration Services agency, “An individual who has received deferred action is authorized by DHS to be present in the United States, and is therefore considered by DHS to be lawfully present during the period deferred action is in effect.” Lawful presence is not to be confused with legal status. DACA did not confer legal status in any permanent way and did not provide a path to legal status. The second benefit to DACA-eligible individuals was the opportunity to obtain work permits and lawfully earn income.

DACA was authorized through the federal government’s executive branch and the prosecutorial discretion of DHS, not legislative action. In September 2017, under a new executive administration and a new attorney general, the 2012 DHS memo was rescinded and DACA was set to phase out. DHS offered a “limited window in which it will adjudicate certain requests for DACA” after September 2017, but otherwise deferred any broad changes in immigration enforcement policy to the legislative law-making process ([Nielson, 2018](#)). The U.S. once again began accepting DACA applications in the summer of 2018, following a court order, although the policy’s future remains in question.

Data

Education records used in this paper come from a mid-size school district covering the years 2011-2018. These data are unique in that documentation status can be inferred accurately, and Hispanic students lacking documentation can then be analyzed separately from those having documentation. We focus on the Hispanic population in this district, not only due to the lack of records for non-Hispanic immigrant students, but also since the vast majority DACA applications come from Latin American birth countries ([USCIS, 2017](#)). For our analysis, a rich set of controls is available, including grade level, age, Free/Reduced Lunch

status, special education status, school demographics, yearly achievement data (standardized test scores), quarterly grade book records, daily attendance, and disciplinary data.

While stipulating the lack of documentation was straightforward in this panel, DACA eligibility has to be inferred using the requirements of the program. To identify students who were likely eligible for DACA, we took the following steps according to the policy requirements. First, we observed that all students in this panel are physically present in the U.S. and under the age of 31, so those qualifications are satisfied. Next, for each undocumented student we identified their earliest record located in the system – formal US entry date, Limited English Proficiency (LEP) entry date, or earliest enrollment date in school – to yield the best approximate date of earliest entry to the U.S. If the earliest record was at least five years prior to June 2012, and their birth date less their earliest record was less than 16 years, the student was then flagged as DACA-eligible.

Available data permit a wide range of analyses. First, we have disciplinary records at the daily-level, combined with more than 100 coded reasons for the infractions. These infractions range from minor disruptions on school-bound buses to major offenses such as battery and assault. Since DACA eligibility might induce a variety of behavioral responses, we compress behaviors into 4 distinct categories: 1) disruptive behavior (collecting all record of defiance, disruption, disorderly conduct, and disobedience) 2) fighting (collecting all forms of fighting, aggressive harassment, battery or threats) 3) alcohol/drug/tobacco violations and 4) actions resulting in suspension (as well as duration of suspension). This gives us a granular picture of responses across the years in our panel.

Second, we use the academic grades of students as recorded at the nine-week level. While grades can represent an equilibrium interaction between students and teachers, we think grades could be an illuminating and timely indicator of students attentiveness in class something standardized achievement might miss. Grades directly affect eligibility for high school graduation as well, which is a key criteria for DACA. If the end of DACA effectively removed incentives for academic progress, we might be able to see this earlier in the panel of GPA records than annual achievement scores.

To condense grades into an analytical framework, we take each student’s nine-week grades and covert into a standard unweighted grade point average metric (GPA) for core classes

only (Math, Science, Social Studies, English, etc.). For elementary students, we are able to calculate this from the numerical grades assigned to each student on their report card. Table 3.1 reports average GPA across the panel of nine-week records.

Third, we have daily attendance data inclusive of excused/unexcused records for each student. We aggregate these data to the monthly level, as it is unlikely that these behaviors would be tightly clustered within student groups, unless there were events to elicit such responses. Instead, it is reasonable to think that behavioral shifts might manifest them in a more dispersed pattern, meaning that aggregating these behaviors makes sense. Table 3.1 lists monthly aggregates for absence and disciplinary infractions, breakout out total infractions into three subcategories.

Empirical Framework

We wish to understand whether DACA-eligible students' academic performance, attendance, and behavior changed following the June 2012 introduction of DACA, or following the September 2017 announcement of its suspension. To do so, we begin with a difference-in-difference empirical model that quantifies within-student changes in those outcomes for DACA students relative to their undocumented peers who are ineligible for DACA, and relative to white, non-Hispanic citizens. For individual i 's outcome in grade g , time t :

$$Y_{igt} = a_0 + \beta_1 DACA_t * DACA_i + \beta_2 LEGIS_t * UNDOC_i + X_{it}\gamma + \theta_i + \theta_g + \theta_t + \epsilon_{igt} \quad (3.1)$$

Y_{it} is a given outcome of interest, whether that be the student's GPA, monthly absences, or disciplinary infraction. The time index t differs by outcome. GPA is measured in nine-week increments with four reporting periods per school year, and is not cumulative. Absences and behavioral infractions are measured monthly. The estimate of interest is $\hat{\beta}_1$, capturing the interaction between the 2012-2017 timing of DACA and those individuals eligible for the program.

The panel of student outcomes overlaps with the introduction of a state immigration enforcement law which allowed local law enforcement to detain and verify the documentation

status of individuals who were suspected to be illegal immigrants (“stop and identify”). Such laws were adopted by many states following Arizona’s 2010 contentious SB 1070. This particular state’s immigration enforcement law affected student absences and withdrawals (Meadows, 2019), at least in the short term, and so we control for its introduction interacted with an indicator that student i is undocumented. Time-varying student controls in X_{it} include indicators for free or reduced-price lunch status. Time-invariant student characteristics for student i , both observed and unobserved, are represented by θ_i , and θ_g and θ_t respectively control for grade and time period fixed effects. Standard errors allow for correlated errors within a given student’s observations.

Identifying variation in β_1 in Equation 3.1 is driven by the introduction of DACA in 2012 (whose effects would first be observed in the 2012-13 school year), as well as its effective halt shortly after the start of the 2017-18 school year. These policy shocks were very different in terms of their content and context, as well as the composition of affected students, some of whom had long since left school by 2017. We might reasonably expect the effect of turning DACA “off” to be asymmetric from the effect of turning DACA “on.” With this in mind, we modify Equation 3.1 to separately identify the interaction between DACA eligibility and the 2012-13 - 2016-17 period from the interaction of DACA with the post-suspension 2017-18 period.

$$Y_{igt} = a_0 + \beta_{1a}DACA_t^{on} * DACA_i + \beta_{1b}DACA_t^{off} * DACA_i + \beta_2LEGIS_t * UNDOC_i + X_{it}\gamma + \theta_i + \theta_g + \theta_t + \epsilon_{igt}, \quad (3.2)$$

where $DACA_t^{on}$ is a binary indicator for the 2012-13 through 2016-17 school years, $DACA_t^{off}$ is an indicator for 2017-18, and their interactions quantify the conditional difference in within-student changes to Y_{igt} for DACA-eligible students during those periods, relative to DACA-ineligible students and students with legal status, and relative to school years prior to 2012.

As an alternative to the pooled models represented by Equations 3.1 - 3.2, we divide the sample into two incompletely overlapping time periods: 2009-10 through 2016-17, and 2013-14 through 2017-18. When we estimate Equation 3.2 for the earlier sample, $DACA_t^{off}$ is necessarily omitted, allowing us to consider the effect of the adoption of DACA ($\hat{\beta}_{ia}$)

in isolation of its suspension. Likewise, when we apply Equation 3.2 to the later sample, $DACA_t^{on}$ and $LEGIS_t$ are omitted, and $\hat{\beta}_{1b}$ estimates the differential response of DACA-eligible students to the end of the program.

Results

Table 3.2 shows a consistent negative relationship between DACA’s timing on DACA-eligible students and their subsequent GPA. This estimate is consistent across specifications, but is not precisely estimated. The relationship between DACA-eligible students’ grades and the suspension of DACA reveals some of the heterogeneity found in the sample. While both estimates are statistically insignificant, the sign of $\hat{\beta}_{ib}$ flips from negative to positive when we move from the pooled sample to the later panel that focuses on the suspension of DACA. While results for the effect of either DACA policy shock on GPA are inconclusive, Table 3.2 results indicate that the state’s immigration-enforcement law may have preceded better performance in class among undocumented students, but by just 3% of mean GPA.

Table 3.3 shows more precision in estimates for monthly absences, which increase during the DACA window *and* following the introduction of the state immigration enforcement law. The estimates indicate 0.10 - 0.13 additional days absent per month during DACA (11.1 - 14.5% of the Table 3.1 mean for DACA-eligible students), with no conclusive reversal of that pattern following the end of DACA. When we limit the sample to students who are present for the suspension of DACA, our estimates of the effect of that policy shock are imprecise and lower in magnitude. DACA-era gains in absenteeism should be interpreted as in addition to estimated effects of the immigration enforcement law, which measured 0.11 - 0.15 days per month across specifications.

The fact that the state law had roughly the same effect on absenteeism for undocumented students as DACA had for undocumented DACA-eligible students, presents an interesting juxtaposition. One policy shifted the risk and salience of deportation up, whereas the other shifted that same risk downwards, yet both led to the same outcome – increased absences. This is where the nuance of DACA’s incentives is particularly relevant. DACA alleviated the risk of detention while traveling to or from school, but it did not incentivize school

attendance beyond what was necessary to complete a high school degree or GED, nor did it necessarily change the risk profile faced by family members of DACA-eligible students. Another possibility is that the law affected which students we can observe over time in the panel. The state law induced more student withdrawals from school (Meadows, 2019), and perhaps students on the margin of withdrawing were less apt to be absent. DACA, on the other hand, may have led students with a high propensity to miss school to persist longer than they would have, in an effort to complete high school and obtain work permits. To analyze this possibility, we split our absence analysis into brackets of students who had 0 absences, 1-2 absences, and 3 or more absences in a month (Table 3.8, 3.9, and 3.10). DACA-eligible students indeed have a decreased incidence of months with zero absences during DACA, a larger effect consistent across specifications, as well as an increased propensity for 1-2 or 3+ absences during DACA, depending on specifications.

Turning to results for disciplinary infractions listed in Table 3.4), there appears to an imprecise and small increase in the monthly volume of all disciplinary citations following the onset of DACA. In the limited post-DACA sample, we again see a different sign on the effect, although the effect of “DACA off” is likewise imprecise.

When we examine a particular type of disciplinary infraction in Table 3.5, fighting, we see that those students eligible for DACA have conditionally more incidents of fighting, by 0.006 - 0.007. These precise point estimates would suggest a small number of additional fights across the DACA-eligible population, but nonetheless a large change to the mean listed in Table 3.1. DACA’s suspension in mid-2017 preceded no statistically significant change in fighting among DACA-eligible students. For other forms of disciplinary action (Tables 3.6 and 3.7) there is a general lack of evidence of differential behavior. Estimates in those tables are small in magnitude and statistically insignificant across models and specifications.

Table 3.1: Summary statistics: GPA, absences, and disciplinary infractions by ethnicity, documentation, and DACA eligibility

	DACA-eligible, undocumented,	DACA-ineligible, undocumented,	Documented Hispanic	White
GPA	2.517 (0.998)	2.635 (1.071)	2.652 (0.994)	2.971 (0.930)
Monthly absences (total)	0.889 (1.105)	0.753 (0.034)	0.802 (0.053)	0.902 (0.045)
Monthly infractions (total)	0.104 (0.393)	0.064 (0.288)	0.095 (0.374)	0.071 (0.326)
Monthly fighting infractions (total)	0.004 (0.065)	0.003 (0.053)	0.005 (0.073)	0.006 (0.080)
Monthly disruption infractions (total)	0.025 (0.181)	0.013 (0.126)	0.024 (0.173)	0.017 (0.150)
Monthly alcohol or drug infractions (total)	0.002 (0.048)	0.002 (0.040)	0.001 (0.034)	0.001 (0.050)

Standard deviations in parentheses

Table 3.2: Estimated effect of DACA on student grade point average

DACA on or DACA off?	Both	Both	DACA on	DACA off
Specification	(1)	(2)	(2)	(2)
School years	2012-18	2012-18	2012-16	2014-18
DACA on $\times$ DACA-eligible	-0.0255 (0.0455)	-0.0356 (0.0505)	-0.0455 (0.0499)	
DACA off $\times$ DACA-eligible		-0.0379 (0.1034)		0.00823 (0.0875)
State immigration law on $\times$ undocumented	0.0595 (0.0386)	0.0695** (0.0343)	0.0792* (0.0343)	

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ **Table 3.3:** Estimated effect of DACA on monthly absences

DACA on or DACA off?	Both	Both	DACA on	DACA off
Specification	(1)	(2)	(2)	(2)
School years	2012-18	2012-18	2012-16	2014-18
DACA on $\times$ DACA-eligible	0.0988** (0.0362)	0.1277*** (0.0381)	0.1291*** (0.0402)	
DACA off $\times$ DACA-eligible		0.1616* (0.0954)		0.0307 (0.0837)
State immigration law on $\times$ undocumented	0.1138*** (0.0341)	0.1398*** (0.0328)	0.1471*** (0.0327)	

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Lastly, a key driver of our results could be withdrawal or persistence during DACA, especially since DACA might have induced students who once were likely to withdraw into staying in school until graduation. Here, our results rely on the merger of two data sets from the school district. The first precedes the current analytical period, and lacks a discrete date of withdrawal/graduation from school. The second (our current panel) includes the date of withdrawal or transfer, which gives a precise estimate of student enrollment behavior. Previous research by [Grogger \(2012\)](#) shows that accurate estimates can be made in data with attrition by attributing trailing strings of zeroes to individuals who have left the panel.

Table 3.4: Estimated effect of DACA on monthly incidence of disciplinary infractions

DACA on or DACA off?	Both	Both	DACA on	DACA off
Specification	(1)	(2)	(2)	(2)
School years	2012-18	2012-18	2012-16	2014-18
DACA on $\times$ DACA-eligible	0.0022 (0.0131)	0.0054 (0.0150)	0.0069 (0.0153)	
DACA off $\times$ DACA-eligible		0.0137 (0.0193)		-0.0025 (0.0202)
State immigration law on $\times$ undocumented	0.0197 (0.0153)	0.0219 (0.0158)	0.0234 (0.0160)	

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ **Table 3.5:** Estimated effect of DACA on monthly incidence of fighting

DACA on or DACA off?	Both	Both	DACA on	DACA off
Specification	(1)	(2)	(2)	(2)
School years	2012-18	2012-18	2012-16	2014-18
DACA on $\times$ DACA-eligible	0.0057*** (0.0014)	0.0064*** (0.0016)	0.0069*** (0.0016)	
DACA off $\times$ DACA-eligible		0.0029 (0.0022)		-0.0023 (0.0019)
State immigration law on $\times$ undocumented	0.0033 (0.0027)	0.0038 (0.0028)	0.0042 (0.0028)	

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.6: Estimated effect of DACA on monthly incidence of disruption

DACA on or DACA off?	Both	Both	DACA on	DACA off
Specification	(1)	(2)	(2)	(2)
School years	2012-18	2012-18	2012-16	2014-18
DACA on $\times$ DACA-eligible	-0.001 (0.0055)	-0.0018 (0.0065)	-0.0013 (0.0066)	
DACA off $\times$ DACA-eligible		-0.0031 (0.0088)		-0.0012 (0.0078)
State immigration law on $\times$ undocumented	0.0055 (0.0072)	0.0050 (0.0075)	0.0049 (0.0075)	

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ **Table 3.7:** Estimated effect of DACA on monthly incidence of alcohol or drug infractions

DACA on or DACA off?	Both	Both	DACA on	DACA off
Specification	(1)	(2)	(2)	(2)
School years	2012-18	2012-18	2012-16	2014-18
DACA on $\times$ DACA-eligible	0.0007 (0.0013)	0.0014 (0.0011)	0.0016 (0.0011)	
DACA off $\times$ DACA-eligible		0.0028 (0.0032)		0.0015 (0.0036)
State immigration law on $\times$ undocumented	-0.0013 (0.0001)	-0.0001 (0.0001)	-0.0008 (0.0007)	

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.8: Estimated effect of DACA on monthly incidence of zero absences

DACA on or DACA off?	Both	Both	DACA on	DACA off
Specification	(1)	(2)	(2)	(2)
School years	2012-18	2012-18	2012-16	2014-18
DACA on $\times$ DACA-eligible	-0.0524** (0.0167)	-0.0706*** (0.0180)	-0.0692*** (0.0187)	
DACA off $\times$ DACA-eligible		-0.0780 (0.0402)		-0.00834 (0.0337)
State immigration law on $\times$ undocumented	-0.0533** (0.0175)	-0.0659*** (0.0178)	-0.0669*** (0.0007)	

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ **Table 3.9:** Estimated effect of DACA on monthly incidence of 1-2 absences

DACA on or DACA off?	Both	Both	DACA on	DACA off
Specification	(1)	(2)	(2)	(2)
School years	2012-18	2012-18	2012-16	2014-18
DACA on $\times$ DACA-eligible	0.0430** (0.0161)	0.0565** (0.0173)	0.0543** (0.0177)	
DACA off $\times$ DACA-eligible		0.0579 (0.0357)		0.00492 (0.0302)
State immigration law on $\times$ undocumented	0.0318 (0.0174)	0.0411** (0.0177)	0.0405* (0.0179)	

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.10: Estimated effect of DACA on monthly incidence of 3 or more absences

DACA on or DACA off?	Both	Both	DACA on	DACA off
Specification	(1)	(2)	(2)	(2)
School years	2012-18	2012-18	2012-16	2014-18
DACA on $\times$ DACA-eligible	0.00570 (0.00519)	0.00989 (0.00541)	0.0114* (0.00583)	
DACA off $\times$ DACA-eligible		0.0179 (0.0116)		0.00824 (0.0337)
State immigration law on $\times$ undocumented	0.00926 (0.00601)	0.0121* (0.00585)	0.0140* (0.0007)	

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In our analysis, we combine both sets of data by compiling all student records from the older administrative panel and extracting a student-date record match from the attendance, gradebook marks, discipline, demographic enrollment, and achievement records. We then take the maximum date of record for each student while ignoring 12th grade students in the month of May – who are likely graduates – and mark this date as the quasi-withdrawal date (or simply the date of last record in school). We then combine these data and re-estimate Equation 3.1 for the effect of DACA on withdrawal behavior. The outcome of withdrawal is a binary indicator, tabulated at both the monthly and semester level. Our results in Table 3.11 show an insignificant and small change in withdrawal behavior during DACA (at the monthly level) and an increased incidence of withdrawal post-DACA.

Discussion and Conclusions

Understanding the outcomes of undocumented students around the U.S. policy of DACA allows a window of understanding into human capital investments respond to shocks in risk, positive and negative. Before the policy, undocumented students were under a general risk of deportation from Immigration and Customs Enforcement (ICE). Upon DACA's initiation, most of this risk was erased for students who arrived in the United States early

Table 3.11: Estimated effect of DACA on withdrawal from school

	Withdrawal (Month)	Withdrawal (Semester)
DACA on $\times$ DACA-eligible	0.00579 (0.00289)	0.0125* (0.00456)
DACA off $\times$ DACA-eligible	0.00634* (0.00249)	0.0234*** (0.00335)
State immigration law on $\times$ undocumented	0.0192* (0.00836)	0.0724*** (0.00196)

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

in life, although the incentives of DACA tilted towards labor market entry rather than post-secondary enrollment (and thus secondary achievement). At DACA’s suspension, the risks to students reverted to their previous level, though this loss of protection might be particularly salient to students.

Existing research on DACA indicates that work permits increased the employment and improved the poverty status of beneficiaries, and that the policy may have changed the composition of undocumented high school graduates (Kuka et al., 2018). By conditioning DACA benefits on high school completion, did the policy motivate K-12 students to improve their grades and behavior? Or did it demotivate them by removing deportation as one (unlikely) risk of missing school or breaking school rules? Our findings thus far are more consistent with the latter mechanism. Following the 2012 onset of the first DACA era, eligible students’ grades remained flat or perhaps declined, while absences and infractions for fighting rose. These patterns did not reverse in 2017-18, when DACA was effectively halted and the current and future treatment of DACA individuals was thrown into question. And yet, our findings are also consistent with shifts in student persistence and withdrawal, if DACA convinced some students with a weaker GPA outlook or imperfect behavior to stay in school longer in hopes of graduating and retaining DACA benefits. Our ongoing work is focused on pinpointing the effects of DACA on high school persistence and completion, and estimates from that work will help us assess whether DACA changed student behavior, or if it changed the students themselves.

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Appendices

A Modeling Eradication with Damages: a simple foundation

We started with a standard generalized dynamic efficiency model, where x is the physical stock of the marketable invasive species and y is the amount harvested in time t . The aggregate growth function $g(x(t))$ shows the net growth of the population (growth less mortality) and λ shows the marginal value of each additional unit of the population at time t . The resource constraint shows that the change in the stock level is equal to the growth function less the harvest.

The net benefits are represented by the generalized function $\pi_t = \pi(x, y)$. A discount rate of ρ is included. Our model is immediately differentiated by $D(x)$ which is the damage function of the presence of the invasive species. This is subtracted from the net benefit function as there will be damages from its existence, but also the possible benefits/profits from sale of the invasive resource.

We begin with our benefits function over time 0 to time T .

$$\max_y = \int_0^T [\pi(y(t), x(t)) - D(x(t))] e^{-\rho t} dt \quad (3)$$

This is subject to the stock's growth rate

$$\frac{\partial x}{\partial t} = \dot{x} = g(x(t)) - y(t) \quad (4)$$

The following properties are assumed

$$y(t) \geq 0, \quad x(T) \geq 0, \quad \pi(0, x) = 0 \quad x \geq 0 \quad \pi_x(0, x) = 0 \quad \pi_x(y, x) > 0 \quad \pi_{yx} > 0 \quad (5)$$

Our Hamiltonian is:

$$H : \pi[x(t), y(t)] - D(x(t)) + \lambda(g(x(t)) - y(t)) \quad (6)$$

With Optimality Conditions

$$\pi_y - \lambda = 0 \quad (7)$$

$$\dot{\lambda} = \lambda(\rho - g_x) - \pi_x + D_x \quad (8)$$

$$g(x(t)) - y(t) = 0 \quad (9)$$

(5) shows that marginal net benefit of harvesting must equal the marginal value of an additional unit of the invasive species. (6) Shows that the combination of the current marginal net benefits and the marginal benefits of unharvested units in the future equal the discounted marginal value of an additional unit in the future. (7) gets our resource to a sustainable position, where growth equals harvest, enabling the resource to be harvested continuously. Importantly, at this steady state, this implies that $\dot{\lambda} = 0$.

We can thus rewrite (6) with the relationship from (5) plugged in.

$$0 = \pi_y(\rho - g_x) - \pi_x + D_x \quad (10)$$

Which rearranged becomes our an updated version of the “Fundamental Equation of Renewable Resources” (FERR) which shows that our optimal steady state values of x and y push the rate of return for the resource to equal the rate of return in the economy. Notice though that our FERR variant takes into account the damages caused by the invasive species.

$$\rho = g_x + \frac{\pi_x - D_x}{\pi_y} \quad (11)$$

Following a similar pathway to [Clark \(1976\)](#) we now insert a simple price-taking profit function $\pi = [p - c(x)]y$ to our FERR above and display the conditions where eradication of

an invasive species would be optimal. Note that p is the market price for the harvest species, $c(x)$ is the cost of harvest and that $\pi_x = c'(x)y$ and $\pi_y = (P - c(x))$. Thus (9) becomes.

$$\rho = g'(x) - \frac{c'(x)y - D_x}{(P - c(x))} \quad (12)$$

Like [Clark \(1976\)](#) two possibilities remain if x is positive. One, eradication is not optimal if either $P < c(0)$ or $\rho < g'(0)$. Two, eradication is optimal if both $P \geq c(0)$ and $\rho > 2g'(0)$.

Let us then define a function of (following [Clark \(1976\)](#) letting $y = g(x)$).

$$H(x) = -\frac{c'(x)g(x) - D_x}{(P - c(x))}$$

So that (10) can be written as

$$\rho - g'(x) = H(x) \quad (13)$$

Now, assume the previous mentioned conditions for optimal eradication hold (both $P \geq c(0)$ and $\rho > 2g'(0)$). Then if no solution is presented when x is non-negative, the proof of optimal eradication is complete. To do so, let us consider the same limiting case of [Clark \(1976\)](#) where $p = c(0)$.

Thus $H(x)$ becomes.

$$\begin{aligned} H(x) &= \frac{-c'(x)g(x) - D_x}{c(0) - c(x)} \\ &= \frac{-c'(x)g(x)}{c(0) - c(x)} - \frac{D_x}{c(0) - c(x)} \\ &= \frac{-c'(x)g(x)}{-(c(x) - c(0))} - \frac{D_x}{-(c(x) - c(0))} \\ &= c'(x)\frac{g(x)}{c(x) - c(0)} + \frac{D_x}{c(x) - c(0)} \end{aligned}$$

Since $f(0) = 0$ and $D(0) = 0$ we can show.

$$= c'(x)\frac{g(x) - g(0)}{c(x) - c(0)} + \frac{D_x - D(0)}{c(x) - c(0)}$$

Define

for some ξ , $x > \xi > 0$

And Apply Cauchy's Generalized Mean Value Theorem to yield the following.

$$\begin{aligned} &= \frac{c'(x)g'(\xi)}{c'(\xi)} + \frac{D''(\xi)}{c'(\xi)} \\ &= \frac{c'(x)g'(\xi) + D''(\xi)}{c'(\xi)} \\ &= c'(x) \frac{g'(\xi) + \frac{D''(\xi)}{c'(\xi)}}{c'(\xi)} \end{aligned}$$

where $D'' < 0$

Rearranged to equal...

$$H(x) = \frac{c'(x)}{c'(\xi)} \left[g'(\xi) + \frac{D''(\xi)}{c'(\xi)} \right]$$

This $H(x)$ would show the following relationship.

$$g'(0) + \frac{D''(0)}{c'(x)} > g'(\xi) + \frac{D''(\xi)}{c'(x)} > H(x)$$

Since $\rho > 2g'(0)$ is a required condition, it can also be shown that ...

$$\rho > 2g'(0) > 2\left[g'(0) + \frac{D''(0)}{c'(x)}\right] + \left[g'(x) + \frac{D''(x)}{c'(x)}\right] > g'(0) + \frac{D''(0)}{c'(x)}$$

And if we conjoin the two terms above, we obtain a similar inequality to [Clark \(1976\)](#).

$$\rho - g'(x) > 2\left[g'(0) + \frac{D''(0)}{c'(x)}\right] - \frac{D''(x)}{c'(x)} > g'(0) + \frac{D''(0)}{c'(x)} > g'(\xi) + \frac{D''(\xi)}{c'(x)} > H(x)^2$$

Namely,

$$\rho - g'(x) > H(x)$$

²by dropping our $2g'(0)$ term and subtracting our $g'(x)$ term from the left side

Or, that (11) has no solution, which completes our proof. Importantly, this result mirrors [Clark \(1976\)](#).

Proposition .1. *When damages are included, eradication is not more likely than when they are excluded. The original non-solution proof of $\rho - g'(x) > H(x)$ in contrast to equation (11) still holds.*

It is important to note that these damages do in fact influence the dynamics of the harvesting of this invasive species, just not the likelihood of eradication in this specific model. We then need to move to more general model to explore other dynamics that damages might influence for the eradication or management of invasive species.

Vita

Benjamin Meadows received his MSEM from Samford Univeristy in Birmingham, Alabama in 2013. As a doctoral student at the University of Tennessee, he has focused on bioeconomics and the economics of education.

During his time in Knoxville, Benjamin has been the Holly Award for Excellence in Presented Research and the Charles B. Garrison Award for Excellence in Teaching. He was also a finalist for the “Three Minute Thesis Competition” for his work in bioeconomics. For his work on education, he was awarded the UT Faculty/Student Research Grant Award. Outside of research and teaching, Benjamin has supported the Haslam Doctoral Student Association, as the Treasurer and later as President.

He is deeply appreciative of the support received by the faculty and staff of the economics department. Each of his projects could not have been completed without their irreplaceable guidance.